Pipeline Persistence: Examining the Association of Educational Experiences With Earned Degrees in STEM Among U.S. Students

ADAM V. MALTESE
School of Education, Indiana University, Bloomington, IN 47405, USA

ROBERT H. TAI
Curry School of Education, University of Virginia, Charlottesville, VA 22902, USA

Received 20 November 2009; revised 3 December 2010; accepted 10 December 2010

DOI 10.1002/sce.20441
Published online 3 May 2011 in Wiley Online Library (wileyonlinelibrary.com).

ABSTRACT: As the global economic crisis continues, sustaining the United States' position as a leader in research and development is a top concern of policy makers. Looking to increase the number of students pursuing degrees in STEM (science, technology, engineering, and mathematics), calls for improved mathematics and science education abound. We completed a two-part analysis to assess the school-based factors related to students choosing to complete a major in STEM. The results indicate that the majority of students who concentrate in STEM make that choice during high school, and that choice is related to a growing interest in mathematics and science rather than enrollment or achievement. These results indicate that the current policy focus on advanced-level course taking and achievement as measures to increase the flow of students into STEM may be misguided. © 2011 Wiley Periodicals, Inc. *Sci Ed* **95:**877–907, 2011

INTRODUCTION

While the total number of bachelor's degrees awarded annually in the United States has nearly tripled over the past 40 years, the same cannot be said for degrees in the STEM

Correspondence to: Adam V. Maltese, e-mail: amaltese@indiana.edu

(science, technology, engineering, and mathematics) fields. Graduation statistics reveal that in 2006 the relative percentages of students earning degrees in nearly all STEM fields were at, or below, previous levels (National Science Foundation [NSF], 2010) (see Table 1). At the same time, the Bureau of Labor Statistics projects that by 2018 the combination of newly created jobs and the retirement of baby-boomers will create more than 3 million job openings in STEM (Lacey & Wright, 2009). In an attempt to address these shortfalls, recent reports and policy initiatives (e.g., Bill H. R. 5116, 2010; Committee on Science, Engineering and Public Policy–National Research Council, 2005) extol the need to increase the rigor of mathematics and science preparation in U.S. schools as a means to bolster the STEM workforce. However, it is not well understood how the suggested interventions will affect the number of students majoring in STEM. These measures appear to be based on the assumption that more students will work in STEM fields if they take more science and mathematics classes or earn higher achievement scores in these subjects. The United States is not alone in its concern about these issues; the European Union issued a major report concerning the need for more scientists to achieve the desired economic growth (European Commission, 2004).

Previous research indicated that students' early career expectations were significant indicators of the likelihood students would complete degrees in STEM (Tai, Liu, Maltese, & Fan, 2006). However, those students who indicated an early interest in science and persisted to earn a degree in STEM accounted for fewer than one in five of the STEM majors from that cohort. If more than 80% of the students entered the path toward a STEM degree after they enrolled in high school, what role did educational experiences, beyond enrollment and achievement, have in their decisions? How educational experiences affect persistence in STEM is the focus of the current analysis.

Framework

This analysis is based on the belief that student aspirations are developed from a combination of intrinsic interest and extrinsic experiences; similar to what Lent, Brown, and Hackett (1994, 2000) call *social cognitive career theory* (SCCT). Lent et al. believe that aspirations and career choices are a result of the complex interplay of person, environment, and behavior. The importance of career aspirations on student persistence in science has been discussed elsewhere (e.g., Mau, 2003; Wang & Staver, 2001), but, since these studies focused on aspirations, they centered on the intentions of students and not long-range outcomes. This study is different—by analyzing the actual academic records and longitudinal surveys of a nationally representative sample of students, it is possible to gain an understanding of how student experiences (i.e., what students experience in their science and mathematics classes), enrollment and performance influenced attitudes and future enrollment in STEM coursework. In turn, the results of this analysis present a clearer picture about the types of experiences that influence student persistence in the STEM pipeline.

Similar to SCCT for career choice, Haladyna, Olsen, and Shaughnessy (1982) argue that student attitudes toward various school subjects are based on student characteristics, teacher characteristics, and the classroom environment. Myers and Fouts (1992) define the classroom environment as "the unique interactive combination of teacher behaviors, curriculum expectations, and student-to-student interactions which develops in the classroom setting" and go on to state "The measure of classroom environment is the individual student's perception of these interactions" (p. 930).

Since the data used in this analysis are longitudinal, it seemed that using a model reflecting the chronological nature of the students' educational experiences was the most logical approach. The work of Cliff Adelman (2006) provided a paradigm for analyzing longitudinal data from the National Education Longitudinal Study of 1988 (NELS:88). By

TABLE 1
Total Number of Bachelor's Degrees and Percentage Awarded by Field, in Selected Years (NSF, 2010)

Year	Total Number of Bachelor's	Non-STEM Degrees (%)	STEM Degrees (%)	Biological/ Agricultural (%)	Geosciences (%)	Mathematics (%)	Computer Sciences (%)	Physical Sciences (%)	Engineering (%)
1966	524,008	80	20	5.7	0.3	3.8	0.0	3.0	6.8
1976	934,443	84	16	7.5	0.5	1.7	0.6	1.8	4.2
1986	1,000,204	79	21	5.0	0.6	1.7	4.2	1.6	7.7
1996	1,179,815	83	17	6.7	0.4	1.1	2.1	1.3	5.3
2006	1,473,735	84	16	6.1	0.3	1.0	2.9	1.1	4.6

evaluating the influence of student attitudes, experiences, and performance over the span of time from adolescence through early adulthood, we attempted to create a model that shed light on how various school-based factors might influence the decision students make to remain in or leave from the pathway toward a degree in STEM.

Previous Research

While there has been recent attention given to STEM education by the current U.S. President (Obama, 2010) and the media (e.g., Dean, 2008), the attention typically focuses on student performance on national or international assessments such as the National Assessment of Educational Progress (NAEP), Trends in International Mathematics and Sciences Study (TIMSS), or the Program for International Student Assessment (PISA). In a recent report, the National Science Board ([NSB] 2008) assessed results from a number of past surveys and assessments. The NSB report mentioned a general improvement of student NAEP mathematics scores, but mixed results on NAEP science scores since the 1990s. On recent international comparisons, students in the United States came in above average on TIMSS and below average on PISA. While these reports offer mixed evaluations of the science and mathematics proficiency of American students, they often neglect to discuss how factors other than achievement may influence student persistence in STEM. With that said, some researchers have concluded that academic performance does play a role in the courses students choose and in career aspirations.

As mentioned, while aspects of the progression through the STEM pipeline have been researched, gaps in the literature do exist. The purpose of this literature review is to present the most salient research on persistence in the STEM pipeline, where it exists. Where there is a lack of studies related to STEM, the goal is to present the best available knowledge in that area. The review begins with an overview of STEM pipeline research with subsequent sections presented in a chronological fashion, starting with research on high school experiences and ending with factors associated with college degree completion.

In general, pipeline studies investigate the notions of attrition from the STEM pipeline (i.e., leaving) and persistence (i.e., entering or staying). Using data from both the National Longitudinal Study of the High School Class of 1972 (NLS:72), and High School and Beyond (HS&B:82), Hilton and Lee (1988) investigated student degree attainment in the sciences. Generally, they concluded that during high school the percentage of students who wanted to pursue further education (i.e., college) in STEM fields was in flux, with approximately equal numbers gaining and losing interest. From their analysis, Hilton and Lee concluded that the greatest overall attrition from STEM came between high school graduation and undergraduate matriculation, generally declining thereafter. Interestingly, our previous work using NELS:88 indicates that the majority (80%) of students who graduate with STEM degrees *enter* the pipeline in high school or college (Tai et al., 2006).

The most thorough research we encountered is work from Adelman (2006), who conducted in-depth analysis of the variables influencing college completion by building a multistep model of persistence. High school curriculum intensity remained significant in predicting college completion throughout all steps of the model; however, the significance of this factor declined as each model progressed farther from high school graduation. Adelman pointed out that this is logical given all the confounding variables that enter the system as students mature. While Adelman's study did not focus specifically on students in STEM, it provides an extensive review of important variables in achievement, persistence, and degree attainment and a strong analytical model.

High School Experiences. The bulk of extant research on the STEM pipeline focuses on the enrollment, achievement, and aspirations of secondary students. A number of researchers focused on the impact of course sequences on student attainment and persistence in STEM. Schneider, Swanson, and Riegle-Crumb (1998) concluded that students with high achievement test scores, few behavioral problems, and parents with high educational attainment expectations were more likely to complete rigorous sequences of mathematics and science than their peers. Madigan (1997) concluded that students taking higher level science courses made greater gains in proficiency on science assessments than other students and indicated that the academic level of courses mattered more than the number of classes completed. Similar work focusing on mathematics course-taking sequences for students in the Education Longitudinal Study: 2002 showed that students made differential gains on mathematics assessments from 10th to 12th grade based on their course enrollment patterns, but the authors note that these gains are substantively minimal when compared to the influence of background characteristics of the students (Bozick & Ingels, 2007). Burkam and Lee (2003) took a different approach and developed "pipelines" based on course enrollments in mathematics, science, and foreign languages. They concluded that students who progressed farther in the mathematics pipeline were more likely to report that they took mathematics courses based on personal interest and were more likely to plan to major in STEM.

Other researchers (Adelman, 2006; Horn & Kojaku, 2001; Trusty, 2002, Tyson, Lee, Borman, & Hanson, 2007) examined the effects of "rigorous" high school coursework on student outcomes beyond high school. The authors of these studies concluded that a more rigorous high school program was significant in students' attainment of college degrees. Tyson et al. (2007) found that (a) women complete more advanced coursework than males, but were less likely to complete the highest level (i.e., advanced physics or calculus) than male students; and (b) significantly fewer Black and Hispanic students completed advanced levels of coursework than their White and Asian peers. Trusty (2002) concluded that female enrollment in advanced mathematics (e.g., precalculus and calculus) and male physics enrollment in high school were positively associated with students choosing to major in mathematics and science. While research indicates that students taking upper level mathematics and science courses in high school were more likely to earn STEM degrees, one point to note here is the serious potential for selection bias in these studies based on the notion that students who are interested in STEM and STEM careers are more likely to enroll in mathematics and science courses based on that interest (Federman, 2007).

Beyond rigorous coursework, Ware and Lee (1988) found that high school grade point average (GPA) and high educational aspirations were positively associated with men and women majoring in STEM. For women, high school factors including a positive attitude toward mathematics and the number of mathematics courses completed were positively associated with a STEM major. High school variables with a significant and positive relationship in predicting male STEM majors were high family socioeconomic status (SES), student rating of their educational experiences, and the number of completed science courses. Maple and Stage (1991) completed a similar analysis, but with a greater focus on differences across racial (i.e., Black and White) groups and concluded that the number of mathematics and science courses enrolled in during high school and the intention to major in STEM (as indicated in 10th grade) were positively associated with students continuing on the STEM pathway in college.

Studies completed outside of the United States investigated high school students' intended college majors and confirmed the importance of high school experiences (e.g., course selection, student enjoyment) on persistence in the STEM pathway. Kidd and Naylor followed three successive cohorts of 10th graders through high school graduation in

Australia, and at each successive grade course enrollments and occupational interest had the greatest direct effects on college intentions for a STEM course path (Kidd & Naylor, 1991). To investigate the formation of students' choices to enter into a science field in college, Cleaves (2005) interviewed UK Year 9 students four times over three years. Interestingly, the students planning to continue study in the STEM fields reported many experiences (e.g., boredom, little talk of career options) they did not enjoy in secondary science. However, because of career aspirations or the flexibility that study in STEM would give them, these students planned to continue in science. Their peers reported similar educational experiences, but for this group the experiences were strong enough to deter them from wanting to continue any study of science and mathematics. Van Langen and Dekkers (2005) looked at international enrollment data and suggested that the number of students enrolling and earning college degrees in STEM may be based on access to the STEM pipeline, where less specialization at earlier stages of secondary and postsecondary education allows more entry points for students along the way.

Classroom Experiences. While the research discussed above shows the impact of coursework and performance on persistence, students have different experiences within each of these classes. Reviews of previous research (e.g., Osborne, Simon, & Collins, 2003) are clear that while most students have positive attitudes about science as an endeavor, they do not hold positive views about the science they experience in the classroom. Osborne et al. conclude their 2003 review by stating that "It is somewhat surprising that so little work has been done in the context of science classrooms to identify what are the nature and style of teaching and activities that engage students" (p. 1074).

On the basis of Myers and Fouts (1992), we define classroom experiences as the pedagogical practices, educational emphases, and achievement outcomes that students experience in their mathematics and science classes during high school. The type of experiences students have in their STEM classes may play a large role in who decides to remain and who leaves STEM (Cleaves, 2005; Munro & Elsom, 2000; Oakes, 1990; Ware, Steckler, & Leserman, 1985); however, these studies shed little light on what classroom experiences impact student persistence. Myers and Fouts (1992) concluded that teachers can improve the attitudes of their students by increasing the number of hands-on activities, coverage of more topics relevant to students, greater use of cooperative learning strategies, the use of varied pedagogical methods, and by providing organization and support. Similar findings by Piburn and Baker (1993) indicated that science students preferred hands-on activities, group work, discussion, and few lectures; they cherished any chance to have input on what topics were studied. Woolnough (1994) conducted a study to determine which factors affected student decisions to continue in science. Some of the significant factors associated with the classroom experiences of students were teacher enthusiasm, placing content in an everyday context, stimulating lessons, and discussion about careers and issues in science. Group work and active learning are pedagogical strategies that have positive impacts on attitudes toward science of all students, but especially for females and ethnic minority students (Oakes, 1990).

College Course Enrollment. Little research exists concerning the mechanisms students use to choose courses at the college level. From students in an introductory biotechnology course in Scotland, Robertson (2000) found that previous employment experiences and satisfaction with doing science were positively associated with enrollment. Gnoth and Juric (1996) examined student enrollment in a marketing course and concluded that the marketing majors were more likely to cite reasons related to competence and future employment as reasons for enrolling, whereas nonmajors mentioned social reasons and fulfillment of credit requirements more frequently—findings supported by work from Babad and others (Babad, 2001; Babad, Hall, & Berger, 1999). Looking specifically at why students enroll in advanced STEM courses, DeBoer (1984) surveyed freshman students after they received their first semester grades. DeBoer concluded that the intention to continue in STEM was positively associated with ratings of personal ability and negatively associated with the ease of the science courses for the "successful" students. In other words, students who felt they had strong ability in science, and that the courses were challenging, were more likely to report plans for enrolling in advanced STEM coursework. DeBoer (1986) completed a follow-up study investigating if there was any difference in how male and female students rated themselves and the association of these ratings with performance and course enrollment. Generally, men and women were equivalent in enrollment and achievement; however, men marked themselves higher in ability based on their completed secondary science courses, and women reported working harder than their male classmates in the college courses. He concluded that students who took more science courses in high school were more likely to give themselves higher science ability ratings, and students with higher ability ratings then completed more science courses in college.

Choice of Major. Beyond selection of individual courses, another set of studies centered on student selection of majors in college. Studies indicate that enrollment, achievement, and attitudes are associated with pursuit of STEM majors. As previously mentioned, at the secondary level positive attitudes toward STEM, high achievement, and advanced coursework are associated with choosing a major in STEM (Maple & Stage, 1991; Trusty, 2002; Ware & Lee, 1988).

While Ware et al. (1985) found that student enjoyment in introductory science courses had a positive association with the choice to major in STEM for all students, they reported differences in other factors based on gender. For the female students, high paternal education level, very high Scholastic Aptitude Test (SAT) mathematics scores, and strong desire for control, prestige, and influence were positively associated with selecting a STEM major. For men, precollege science major intentions and high grades in freshman science were positively associated with a major declaration in STEM, whereas paternal education level had a negative relationship. Interestingly, women and men in the sample reported nearly identical educational experiences, but only 31% of the women reported that science was their most enjoyable class (49% of the men reported this), reminiscent of findings by Cleaves (2005). Using data from NELS:88 and from HS&B:82 to investigate student selection of STEM majors, Federman (2007) included a few variables in her model to account for student interest in science and mathematics. Her results indicate that early mathematics and science achievement, advanced course enrollment, and students' reports of science being useful in their future were all associated with an increase in the likelihood of students' completing a college degree in a STEM field.

College Persistence. In terms of general college persistence, Tinto (1993) argues that the rigor of high school preparation and, more importantly, student intentions play a large role in student retention. Sullins, Hernandez, and Fuller (1995) explored student persistence in college biology and concluded that student interest was a significant predictor of student intentions to major in biology. Seymour and Hewitt (1997) completed a qualitative investigation of student attrition from STEM fields once in college. Many of the students reported entering college with plans to major in STEM because of their positive experiences in high school science; however, once matriculated, many students reported leaving the sciences because they lost interest or had negative experiences in their college courses. Rose and Betts (2001) analyzed HS&B:82 data to delineate how the completion of high school mathematics classes affected career earnings. The authors determined that completion of advanced mathematics coursework in high school was positively associated with college degree completion, and the association was stronger than similar measures for courses in other areas, including science. Astin and Astin (1993) used data from more than 26,000 college students to investigate the factors associated with choosing and remaining in STEM throughout college. The researchers found student intentions to major in STEM, collected during freshman year in college, was the strongest predictor for those who completed degrees in science and engineering. Supporting this, work by Bonous-Harnmarth (2000) indicates that for all racial groups, intent to major in STEM fields (measured in freshman year) was more strongly associated with persistence than was the strength of high school GPA or SAT scores. Astin and Astin also reported that students with science-based career aspirations, strong achievement in mathematics, higher ratings of science orientation, higher numbers of peers majoring in STEM fields, and those enrolled in courses with student-oriented faculty were more likely to complete majors in STEM.

While not specifically focused on STEM, research by Bozick and DeLuca (2005) indicated that students who were married prior to or during enrollment in college had lower odds of degree completion than their unmarried peers. In addition, Ishitani (2006) reported that student participation in loan programs and work-study can have varied effects on college persistence and time to degree.

Pipeline Differences Based on Gender and Race. Research indicates differences in the persistence of students based on gender and ethnicity. When looking at high school course-taking, women complete more advanced coursework than males, but are less likely to complete the most rigorous courses (Tyson et al., 2007). While data indicate that since 2005 more baccalaureate degrees in STEM go to women, these degrees are not equally distributed—in 2009 females completed 72% of the degrees in the life sciences (majority since 1976), whereas males completed more degrees in the physical sciences (58%), geosciences (61%), mathematics and computer science (74%), and engineering (82%) (NSF, 2010). Looking at differences in enrollment from an international perspective, Van Langen and Dekkers (2005) propose that the greater enrollment of women in STEM in some countries may be a result of a longer history of gender equality legislation in those nations. In terms of attrition, Hilton and Lee (1988) found the rate of attrition from STEM was lower for females than for males, but in their analysis male students outnumbered females roughly two to one in STEM.

Across race categories, research indicates that White and Asian students earned the majority of degrees in STEM in the United States, but large gains were made in the numbers of women and minority groups earning degrees over the past 30 years (Adelman, 2004a; Hilton & Lee, 1988). Other data indicate that roughly equal percentages of White, Black, and Hispanic students who complete college earn degrees in STEM (Tyson et al., 2007). While there is attrition of students from all racial groups, findings indicate that students from underrepresented groups are more likely to leave STEM majors (Bonous-Harnmarth, 2000). Because attrition from STEM fields drops significantly once students matriculate, Hilton and Lee (1988) argue that the growth in interest for underrepresented students at the secondary level is critical to greater representation in these fields.

Career Aspirations. Previous research indicates that from an early age (i.e., middle school), interest in pursuing a career in STEM may provide the momentum to carry students through the pipeline (Cleaves, 2005; Kidd & Naylor, 1991; Maltese & Tai, 2010; Tai et al., 2006). An analysis of Longitudinal Study of American Youth data indicated that among a wide variety of factors, instructional quantity, student achievement and attitude toward science held significant associations with career aspirations in science fields (Wang & Staver, 2001).

Mau (2003) looked at the effects of gender and race on the persistence of aspirations to follow a career in science and engineering and concluded that gender and race, mathematics self-efficacy, and academic proficiency played a significant role in the persistence of career aspirations. Advancing this work, we investigated the association of student interest with college major choice (Tai et al., 2006). After accounting for student background and academic achievement in mathematics, students indicating a preference for a career in STEM fields were two to three times more likely to graduate college with degrees in the sciences than their peers who did not indicate such a career expectation.

Limitations of Existing Research

There are a few major limitations with the existing research. First, most investigations on the impact of high school factors on college outcomes did not use data that provided "definite" outcomes. For example, rather than looking at the actual major students completed, most studies included student intentions measured before they earned degrees (e.g., Kidd & Naylor, 1991; Trusty, 2002). Second, many studies involved data collection from only a single university (e.g., Babad et al., 1999; DeBoer, 1986) or a single class (e.g., Gnoth & Juric, 1996; Robertson, 2000). As a result, these studies involved small sample sizes and have limited generalizability.

For the studies that used longitudinal data with concrete outcomes, most focused on high school GPA and SAT scores and ignored (or did not have available) the rich data providing information on students' educational experiences and interests (e.g., Schneider et al., 1998; Tyson et al., 2007). In addition, while Adelman (2006) provided the most detailed analysis of students moving from high school through college, he did not focus on those in STEM and therefore did not include many variables that examined student experiences in mathematics and science at the secondary level. With this study, we seek to fill this gap in the research and assess the relationship between students' classroom experiences in high school science and mathematics and college course enrollment in STEM.

In prior work (Tai et al., 2006), we examined the association between declared career aspirations by middle school students and their likelihood to earn degrees in science and engineering. In that study, we did not examine the intermediate steps in the STEM pathway during high school and college. Building upon that work, the current study examines intermediate educational factors including course enrollments and performance in the years between eighth grade and college completion. In addition, this analysis examines the educational experiences of baccalaureate degree earners with STEM concentrations who did not declare science-related career aspirations in eighth grade, an important analysis not undertaken in the earlier research; especially since approximately 80% of STEM concentrators did not declare an early career interest in a STEM career.

Methodology

Data Set. These analyses were completed using data from 4,700 students in U.S. schools who participated in NELS:88.[1] Data from NELS:88 were used because this data set is

[1] NCES collected data from a nationally representative cohort of students in 8th grade with follow-up surveys in 10th grade (1990), 12th grade (1992), and at 6 and 12 years beyond 8th grade (1994 and 2000–2001). For more information on NELS:88, please refer to the NCES Web page at nces.ed.gov/surveys/nels88/.

nationally representative and offers the most recent and comprehensive set of information concerning students' school experiences and outcomes in mathematics and science for the critical period between eighth grade and college completion. The NELS:88 data provide information on students' enrollment, achievement, experiences and attitudes, as well as academic and career plans. In each of the first three surveys (i.e., 8th, 10th, and 12th grades), students were asked to report on issues including their level of interest in specific subjects, the amount of class time spent engaged in specific activities, how challenging they found the material, and the types of instruction they received. Students included in this analysis participated in all five survey rounds and had valid high school and college transcript records. These transcript records, part of a restricted data set, allowed us to account for each class taken by students in high school and college and included pertinent information such as the level of the classes and earned student grades.

Analytical Approach. The focus of this analysis was to explore variables associated with student persistence in the STEM pipeline, with particular attention paid to factors influenced by schools. For this reason and to minimize missing data, variables outside of the school domain (e.g., parental aspirations for child) were not central to this assessment and were not included. Although NELS:88 collected data from students' parents, teachers, and school administrators, this analysis only uses survey data provided by students. Similar to Myers and Fouts (1992), we believe that it is students' perceptions of what occurs in the classroom that are most important to consider, for it is these perceptions that will guide students when contemplating further enrollment in STEM. In addition, we believe that there is greater potential for bias in the teachers' responses based on issues involving social desirability than in the student responses (Kopcha & Sullivan, 2007).

Some readers may feel that there is an issue with the validity and reliability of self-report data from students regarding their experiences in the high school classroom. This is a legitimate concern; however, the focus of this research is on what students perceived and on what they accomplished. The reliability of self-report data provided by students has been discussed in the literature, and findings indicate that students with stronger academic records, especially those who attend college, generally provide valid and reliable information regarding their academic experiences (Bahrick, Hall, & Berger, 1996; Fetters, Stowe, & Owings, 1984; Kuncel, Credé, & Thomas, 2005).

Outcome Measure. A bachelor's in a STEM discipline is usually an entry requirement for work or graduate education in a STEM field, and therefore, it effectively creates a filter in the pipeline. We originally planned to use the major field listed on transcripts as the outcome measure, but missing data regarding earned bachelor's degrees meant that the number of complete cases was limited. To deal with this limitation and others caused by institutional transfers, other studies (e.g., Adelman, 2004b, p. 137, 2006, p. 191) have mentioned the use of a minimum number of credits as a measure indicating the likelihood that a student completed a degree with a major in a given field. Accordingly, we decided to use the number of upper level STEM courses (i.e., nonintroductory courses that count toward major) completed as an indicator of a student earning a degree within the discipline (see Table A1 for classification of fields).

Before we chose to use upper division coursework as a proxy for earned baccalaureate degree, we performed several analyses to validate this approach. First, when we look at those NELS:88 sample members with transcripts indicating STEM degree ($n = 980$) the mean number of upper level STEM courses completed by these students is 15.

Second, we decided on an appropriate threshold of courses by randomly selecting 20 schools from the lists of top liberal arts colleges and national universities provided in the annual review in *U.S. News and World Report* (2008). After selecting 10 schools from each list, we reviewed the requirements for completion of a major in one of the STEM fields at each school. The number of courses required to complete a major ranged from 10 to more than 20, with a mean value of 16 classes.

On the basis of these two steps, we decided to set a conservative threshold such that students completing 16 or more upper level courses in STEM were labeled as pursuing a major in STEM, whereas those who completed 15 or fewer upper level classes were labeled as non-STEM majors. In addition, any student who did not meet the threshold, but had a STEM major listed on their transcripts, was placed in the STEM majors' category. To simplify discussion of this variable throughout the remainder of this presentation, students completing 16 or more classes in STEM will be labeled STEM majors.

To evaluate the validity of creating this outcome measure, we reviewed the proportions of students in the NELS:88 data with an "official" STEM major listed on their transcript, those who met our 16-course threshold, and the percentage of students who earned STEM degrees between 1996 and 1998 according to NSF IPEDS completion data (see Table A2; NSF, 2010). The data show that using a sample consisting of students who met the 16 course threshold resulted in a cohort that is nearly identical to the demographic makeup of the "transcript" sample, but is closer to the actual NSF figures for percentage of degrees earned in STEM than if the selection was based solely on the valid transcript subsample. On the basis of these findings, we decided that a solid, conservative estimate to use would be 16 upper level courses in STEM as a proxy for a STEM bachelor's major.

Control Measures. Nearly all of the studies reviewed control for a student's gender and race/ethnicity, as well as some measure of SES. Studies that have assessed the effect of gender and race on STEM persistence and achievement have come to varied conclusions as to their effect on a given outcome (e.g., Bonous-Harnmarth, 2000; Hilton & Lee, 1988; Mau, 2003). For this reason, and for the fact that females and non-Asian/non-White students are typically underrepresented in most STEM fields, these variables are included in the analysis at all stages. Measures of SES have been used in a number of studies with some results (e.g., Ware & Lee, 1988), indicating that SES was a significant predictor of students pursuing STEM majors. As a proxy for SES, we included parental education level since it is strongly associated with family SES (Davis-Kean, 2005) and is often used as an indication of the type of environment a student may be exposed to at home (e.g., Federman, 2007; Goyette & Mullen, 2006).

Predictors.[2] The studies we reviewed provide a solid foundation from which to build our analytical model. Significant findings provide an indication of the constructs or factors that may be influential in various aspects of student experiences as they progress through the STEM pipeline. What follows is a brief review of the research that provides a basis for our inclusion of predictor variables in our analysis.

There are indications that student interest in science and mathematics, measured in different forms, plays a role in persistence. Ware and Lee (1988) concluded that both educational aspirations and a *positive attitude toward mathematics and science* were positively

[2] Throughout this section, text appearing in *italics* refers to related items included in the analyses. Readers interested in the specific items and response options for the variables included in this analysis are urged to review the NELS questionnaires or request data from NCES through their Web site at nces.ed.gov/surveys/nels88/. For a list of all the variables used, please contact the authors.

associated with student selection of a STEM major. Looking at student interest in the form of *career aspirations*, numerous studies (e.g., Tai et al., 2006; Cleaves, 2005; Sullins et al., 1995; Wang & Staver, 2001) concluded that student interest in a STEM career is strongly associated with persistence in STEM. Variables that provide a measure of the importance of science (i.e., *Mathematics is useful*, *Look forward to science class*) have been shown to be significantly associated with positive student attitudes toward science (Haladyna et al., 1982, 1983) and degree completion (Federman, 2007). In addition, other research indicates that secondary and postsecondary students made enrollment decisions based on their *intended college major* or whether course content would be useful toward their future pursuits (Babad, 2001; Gnoth & Juric, 1996; Kidd & Naylor, 1991).

Another set of factors commonly reviewed are student enrollment and performance in science and mathematics courses. Substantial previous research indicates that the *number of mathematics and science courses* enrolled in high school was positively associated with students continuing on the STEM pathway in college (Burkam & Lee, 2003; DeBoer, 1986; Maple & Stage, 1991; Trusty, 2002; Ware & Lee, 1988). Researchers have also focused on the academic level (i.e., *basic, general,* and *advanced*) of courses completed by students, and most concluded that a more rigorous program of high school courses was positively associated with completion of a college degree (Horn & Kojaku, 2001; Trusty, 2002).

Achievement variables are nearly ubiquitous in the STEM literature, most often being used as outcome measures. Research demonstrates that indicators of mathematics/science performance in the form of *grades* (Ware & Lee, 1988) or subject-specific *achievement test scores* (Federman, 2007) predicted higher likelihood of students completing a major in STEM fields.

Classroom Variables

The interplay of classroom experiences, student interest, and persistence is the crux of this study. Findings from Myers and Fouts (1992), Piburn and Baker (1993), and Woolnough (1994) offered similar results indicating that teachers may improve the attitudes of their students by increasing the number of hands-on activities (e.g., *often use hands-on materials*), coverage of more topics relevant to students (e.g., *make choice of science topic to study*, *emphasis on importance of mathematics in life*), greater use of cooperative learning strategies (e.g., *often participate in student discussions*), the use of varied pedagogical methods (e.g., *listen to the teacher lecture in science*, *often use computers in mathematics class, write reports of laboratory work in science*), and discussion about careers and issues in science (e.g., *discuss careers in scientific fields*). In combination, these studies point to specific classroom practices and emphases that improve student attitudes toward science. In this study, we use variables related to these factors (noted in italics above) and additional measures of pedagogical practice (e.g., *often explain mathematics work in class orally*, *use computers for science models*) and emphasis (e.g., *emphasis on ways to solve mathematics problems*, *emphasis on learning science facts/rules*) to evaluate their relationship with student persistence to completion of a degree in STEM.

Postsecondary Factors. Once students graduate from high school, any type of *delay in enrollment* in postsecondary education may have a negative impact on degree completion (Adelman, 2006). These delays may be associated with decisions to enter the workforce, but they may also be influenced by other factors including *marriage* or *becoming a parent* (Bozick & DeLuca, 2005). Other research indicates that *financial aid* and involvement in *work-study programs* may influence degree completion (Ishitani, 2006). Although there are no NELS:88 variables regarding student experiences in their college classrooms, we included data from transcripts on *course enrollments* and *performance* that we believed could yield information about factors influencing persistence in STEM.

Logistic Regression Model. To reiterate, the goal of this analysis was to investigate the role that educational experiences in science and mathematics had on student persistence in the STEM. To accomplish this, we created a progression of logistic regression models to assess predictor variables including student enrollment, achievement, and experiences. The logistic models provided information about the associations between these predictor variables and the outcome of completing a major in a STEM field.

On the basis of the approach used by Adelman (2006), we built the logistic model in chronological blocks (i.e., background, 8th grade, 9th grade, 10th grade etc.) to assess the role that each step played as students progressed toward degree attainment. Since interest in STEM may account for many differences in coursework, and performance and effort in classes, indications of early interest in STEM—measured in eighth grade—are included in the model prior to blocks involving high school experiences. To assess their effects on the completion of a STEM major, the following blocks of predictor variables were entered into the logistic regression model:

Block 1a. *Background variables:* Gender, race, parental education level;

Block 1b. *Early attitudes toward mathematics and science*: variables to account for a student's "starting" position in proficiency and attitudes toward science and mathematics;

Block 2–3. *9th- and 10th-grade variables*: transcript data provide information on class type, credit, and grades for STEM classes completed in 9th and 10th grades; 1st follow-up surveys provide information on student experiences and attitudes in 10th grade;

Block 4–6. *11th- and 12th-grade variables, planned major*: similar to the *Block 2/3* variables; second follow-up surveys also provide information on intended college major and achievement measures; 11th- and 12th-grade enrollment, grades from transcripts;

Block 7. *Postsecondary variables:* enrollment in advanced courses, grades; third follow-up surveys provide: life experiences (e.g., marriage, delay in college attendance), career intentions.

Building the regression model in this fashion allowed us to examine how the relationships between significant variables and the dependent variable evolved as additional factors, more proximal to the outcome, were added. Using NELS:88 data, regression techniques cannot provide a definitive answer on what factors cause students to leave STEM. Through regression, it is only possible to assess the relationships between indicator variables and the outcome measure—to determine whether any change in a given factor is associated with a significant change in the outcome variable.

Traditionally, the calculation of logistic regression models can present a variety of statistics including log odds, odds, and probabilities. All of these have their strengths and limitations in terms of interpretation of the results. Another measure commonly presented in the research literature is the odds ratio, which is a measure of association between a given factor and the possible outcomes. Odds ratios provide an indication of how much more (or less) likely an outcome is based on the existence or absence of a given factor (Hosmer & Lemeshow, 2000, p. 50). Therefore, in this work the association between factors and outcome measures will be discussed as odds ratios.

When analyzing the influence of multiple independent variables, the issue of collinearity is an important consideration. Collinearity is caused by the inclusion of highly correlated independent variables in regression models, and can wreak havoc with interpretation of model results (Pedhazur, 1997). Therefore, for each block of variables analyzed in the logistic models, collinearity statistics were calculated. Any variables with sufficiently high collinearity (i.e., tolerance = 0.5, lower tolerance values indicate stronger collinearity) were investigated. Issues arose most often when a large set of variables was placed in the model or when variables measuring similar attributes (e.g., *mathematics Item Response Theory Scale [IRT] scores* from Grade 10 and Grade 12) were in the model simultaneously. In all cases where predictors failed the tolerance test, the collinearity issue was resolved by paring the model down to include only significant factors, which dropped collinear variables from the model.

Analysis of enrollment patterns and associated performance and experiences provided an interesting problem for analysis.[3] Any time students were not enrolled in a science or mathematics course throughout high school, they did not have data available for course grades or for other variables concerned with classroom experiences. These "legitimate skips" created a problem in the model. Since these cases were skips and not data that were missing at random, it was not possible to impute values, which effectively cut these cases out of the analyses. Because of this situation, we decided to proceed using two layers of analysis. The primary models only included variables for enrollment and standardized achievement measures. This limited problems caused by a shrinking data set. In addition, we included secondary models to assess the association of classroom experiences and performance. These secondary models were constructed with significant variables from the primary models and the addition of student grades, course level, and student reports of their academic experiences (available for 10th and 12th grades). These secondary models limited the number of sample members available for analysis, but provided an important evaluation of common practices that may influence student decisions to persist in STEM.

To assess the effect of course enrollments, we used dummy variables for the most common science and mathematics courses completed by students during high school. These are not dummy variable sets, rather they are dichotomous variables that indicate whether or not (0 = no, 1 = yes) a student was enrolled in a given class during a given year. For example, Bio9 indicates if a student was enrolled in a biology course, at any academic level, during the ninth grade. Coding the enrollment this way allows more flexibility in the model to uncover interactions—rather than trying to create variables accounting for the near-limitless number of course combinations found in the data. Table 2 provides the percentage of students enrolled in each of these common courses at each grade level. The data indicate that 10th-grade biology and 11th-grade chemistry are the two most common science courses students completed during high school. For mathematics, the majority of students enrolled in algebra during 9th grade, whereas a significant number of students completed geometry during their 10th-grade year.

As previously mentioned, the complex sampling design of NELS:88 requires the use of weights to properly calculate standard error terms for each variable. In essence, weighting the sample allows a researcher to generalize the results of statistical models to a wider range

[3] Analyzing longitudinal data in this fashion leads to censoring issues when students do not provide responses for each item in the analysis. If a student completed all rounds of surveying but did not take a science or mathematics class during either 10th or 12th grade, they would be considered a "legitimate skip" for those variables. This "In" or "Out" status is acceptable for analyzing enrollment patterns, but when analyzing the frequency of different pedagogical occurrences experienced by the student (e.g., using calculators, listening to lecture) it is not valid to impute null values for all of these variables. Since imputation is not valid these cases, the models consider them to be missing data for these variables and they are dropped from the analysis.

TABLE 2
Percentage of Students Enrolled in Common High School Science and Mathematics Courses ($n = 4{,}690$)

Grade	Biology	Chemistry	Physics	Earth Science	
9	30.50	0.15	0.61	13.26	
10	64.93	20.63	1.69	1.95	
11	9.36	56.57	12.51	1.62	
12	10.10	12.72	29.66	1.85	
	Algebra	Geometry	Trigonometry/Algebra II	Precalculus	Calculus
9	65.47	17.01	0.39	0.16	0
10	39.42	50.01	3.83	0.38	0.25
11	43.28	19.20	16.55	14.09	2.23
12	15.89	6.20	13.97	16.96	18.43

of the population. The NELS:88 sample was designed to be representative of the population of students in 8th, 10th, and 12th grades. Because our sample includes students who had high school and college transcripts, we selected a weight that was created for students who were 12th graders in 1992, had full high school transcript records, and either collected or imputed college transcripts. Use of the sample weights allows for a correction to be made in the standard errors, which then produces accurate significance calculations. Data were analyzed using *STATA 10.1*, a software package that can produce proper estimates based on complex sampling.

Throughout this discussion of results, any variable identified as significant has a p-value of .05 or lower. As the analysis was built in blocks, any variable with a p-value of $<.06$ was kept in the model, whereas others were discarded before adding in the next block of variables. All of the logistic regression models presented here used college degree in STEM versus non-STEM as the dichotomous outcome measure.

Sample. The data for this study come from a sample of approximately 4,700 students who participated in NELS:88 and had completed all surveys and provided transcripts from eighth grade (1988) through to their midtwenties (2001). The majority of students in the sample were female (53%), with 97% of the sample between the ages of 14 and 15 when the study began. The sample was predominantly White (81%), followed by Black (7%), Hispanic (6%), Asian/Pacific Islander (5%), and American Indian (<1%). Students were educated in all 50 states, and 97% were from households where English was the dominant language. The majority (87%) of students attended public high schools, and an identical proportion had a parent with some level of postsecondary education.

Results

The results of each logistic block are discussed below. For simplicity, we may refer to variables discussing mathematics or science, but whenever we mention including variables in the model for one subject (e.g., mathematics), comparable variables for the other subject (e.g., science) were also included. To conserve space, not all models are presented in graphic form. This section ends with a discussion of significant results from the models.

Background Variables. The first block of variables entered into the model includes demographic variables common to most analyses: gender, race/ethnicity, and parental education level as a proxy for socioeconomic status. With only these background variables in the model, any relationships with the outcome measures are extremely tentative.

At this stage, there was a negative association between both female and American Indian students and a degree in STEM. Asian students were more likely to complete the required coursework for a STEM degree, but parental education level was nonsignificant. Regardless of model significance, all background variables are retained in the model through all stages.

Early Attitudes Toward Mathematics and Science. The next block of variables was used to account for a student's "starting" position in proficiency and attitudes toward science and mathematics using data collected during eighth grade. Students were asked to indicate how strongly they agreed with statements regarding the usefulness of mathematics, whether or not they were afraid to ask questions in class, and if they usually looked forward to mathematics class. Students were also asked a question about the careers they desired at age 30. The response categories for this question were categorized into STEM and non-STEM careers and used as a dichotomous predictor variable similar to that used by Tai et al. (2006) (see the Appendix for categorization). In addition to factors that provide an indication of early attitudes, three achievement measures were included in the model to provide baseline measures of student performance on standardized tests in science, mathematics, and reading.

After adding the interest and performance variables into the model, the only background variable achieving significance was a positive relationship between Asian students and earning a degree in STEM (Table 3). In addition, students who earned higher scores on eighth-grade science and mathematics achievements were more likely to complete degrees in STEM, as were those who agreed that science would be useful in their future. Students who indicated that they desired a job in a science or mathematics field when they reach age 30 were also significantly more likely to complete STEM degrees.

9th- and 10th-Grade Class Variables. The first major block of variables included in the analysis is from transcript data that provide information on class type, credit, and grades for STEM classes completed in 9th and 10th grades. When ninth-grade enrollment variables are added to the model, the predictors for science and mathematics achievement as well as interest in science remain significant. In addition, students completing geometry in ninth grade were more likely to complete a degree in STEM than their peers who were enrolled in other classes. A secondary model included grades, the number of classes, and the level of classes students completed. The predictors already mentioned remained significant, and the variables for student grades in ninth-grade science and mathematics had a moderate positive association with earning a degree in STEM.

Data for students in 10th grade included variables for enrollment and performance as well as information on students' experiences and attitudes regarding science and mathematics. The data indicate that the inclusion of 10th-grade achievement scores and coursework drops the 8th-grade achievement scores and 9th-grade geometry from the model. Even after the inclusion of the 10th-grade variables, students who believed science would be useful and those who desired science careers in 8th grade were more likely to earn degrees in STEM. It is important to note that follow-up surveys for NELS:88 did include a question asking students what employment they desired at age 30; however, because the response options

TABLE 3
Summary of Logistic Regression Analysis Predicting Completion of a Degree in STEM: Background variables

Predictors	Odds Ratio	*SE*	*t*
Female	0.93	0.10	−0.69
American Indian/Alaska Native	0.21	0.21	−1.57
Asian/Pacific Islander	1.55*	0.28	2.47
Hispanic	0.78	0.14	−1.36
Black	0.80	0.21	−0.86
Highest level of parental education	0.99	0.04	−0.24
Mathematics IRT estimated numbers right (G8)	1.04***	0.01	4.79
Science IRT estimated numbers right (G8)	1.05**	0.02	2.74
Reading IRT estimated numbers right (G8)	0.99	0.01	−0.86
Science useful in future (G8)	1.72***	0.27	3.52
Afraid to ask questions in science (G8)	0.75	0.13	−1.72
Look forward to science class (G8)	1.08	0.14	0.61
Mathematics useful in future (G8)	0.79	0.18	−1.01
Afraid to ask questions in mathematics (G8)	0.94	0.12	−0.52
Look forward to mathematics class (G8)	1.17	0.13	1.34
Expected career in STEM at age 30 (G8)	1.97***	0.28	4.85

Note. $n = 4{,}350$ (population size = 884,580); $F(16, 827) = 11.89$, $p < .001$.
$^{*}p < .05$, $^{**}p < .01$, and $^{***}p < .001$.

for the questions were quite different than the earlier version of the question, it was not possible to delineate STEM/non-STEM categories.

When variables are entered into the model to indicate the number and level of courses completed and student grades, the 10th-grade mathematics achievement score loses significance and is replaced by average grades for 10th-grade science and mathematics. Inclusion of these variables in the secondary analysis showed that female students were significantly less likely to earn degrees in STEM.

The overarching goal of this analysis was to assess how student experiences in their high school science and mathematics classes affected their persistence in the pipeline. The 10th-grade data collection was the first of two surveys where students were asked to report on their experiences and attitudes regarding science and mathematics. Inclusion of these variables in a secondary model sheds light on how common pedagogical practices and students attitudes might have influenced student persistence. As shown in Table 4, only three variables (of 48 entered) remained significant after iterating the model and removing factors that lacked significance. For students who took more time to complete science homework and for those who indicated that mathematics was one of their best subjects, there was a greater likelihood of completing a degree in STEM. Interestingly, students who reported that there was a strong emphasis on learning facts and rules in mathematics class were less likely to persist to a degree in STEM.

11th- and 12th-Grade Variables. The blocks including 11th- and 12th-grade data were incorporated into the model in an identical fashion to those for the 9th and 10th grades. Building up from the background variables and retaining variables that maintained significance through 10th grade, the addition of enrollment variables for 11th-grade coursework resulted in a number of classes having a strong positive relationship with earning a degree in STEM. Students enrolled in biology, chemistry, or trigonometry/Algebra II were more

TABLE 4
Summary of Logistic Regression Analysis Predicting Completion of a Degree in STEM: Grade 10 Experiences and Attitudes

Predictors	Odds Ratio	*SE*	*t*
Female	0.90	0.09	−1.06
American Indian/Alaska Native	0.27	0.27	−1.30
Asian/Pacific Islander	1.48*	0.27	2.18
Hispanic	0.76	0.15	−1.44
Black	0.86	0.24	−0.54
Highest level of parental education	1.01	0.04	0.31
Science useful in future (G8)	1.79***	0.23	4.50
Expected career in STEM at age 30 (G8)	2.02***	0.28	5.13
Mathematics IRT estimated numbers right (G10)	1.04***	0.01	7.59
Emphasis on learning facts/rules in mathematics (G10)	0.86*	0.05	−2.44
Total time on homework—science (G10)	1.04*	0.02	2.28
Mathematics is one of my best subjects (G10)	1.62***	0.20	3.92

Note. $n = 4{,}170$ (population size = 849,260); $F(12, 837) = 16.50$, $p < .001$.
*$p < .05$, **$p < .01$, ***$p < .001$.

likely than their peers to earn degrees in STEM. In this model, students enrolled in biology were 2.5 times more likely to complete STEM degrees than other students not enrolled in 11th-grade biology, interesting because this includes fewer than 9% of the students in the sample. The addition of performance and course-level variables resulted in the 11th-grade mathematics and science grades being significant at the expense of all 11th-grade courses mentioned above.

In addition to the significant predictors from previous models, the first 12th-grade variables assessed were those regarding student enrollment. Based on the pattern developed over the previous blocks, it was not surprising that enrollment in certain science and mathematics courses was a significant predictor of a major in STEM. Biology, chemistry, and physics were all associated with a greater likelihood of students majoring in STEM, as were trigonometry/Algebra II and calculus. Of all the enrollment variables reaching or maintaining significance, it is interesting that 11th-grade biology remained the strongest predictor of STEM degree completion. The 10th-grade mathematics achievement score loses significance, but is replaced in the model by the 12th-grade test, which is a weak, but positive predictor of students earning a degree in STEM. When course-level and performance indicators were entered into the model chemistry, trigonometry/Algebra II and calculus remained significant, as well as 12th-grade mathematics and science averages.

As in the 10th-grade, the 12th-grade survey asked students to provide information about experiences in mathematics and science. These variables were included in a secondary model to assess their significance, and all significant variables from prior models were kept in the analysis. Beginning with a model including all 12th-grade mathematics and science variables related to student experiences, predictors not reaching significance were dropped out of the model one at a time. Each set of similar variables eliminated allowed more respondents back into the analysis. This iterative process resulted in a handful of variables concerned with pedagogical methods becoming significant (Table 5). Using hands-on materials in mathematics class was positively related to students persisting to a degree in STEM; however, students who reported frequent use of computers in mathematics class were less likely to earn STEM degrees. In science, students who reported more frequent lecturing by their teacher and those who reported frequent use of books to indicate how

TABLE 5
Summary of Logistic Regression Analysis Predicting Completion of a Degree in STEM: Grade 12 Experiences and Attitudes

Predictors	Odds Ratio	*SE*	*t*
Female	0.84	0.12	−1.28
American Indian/Alaska Native	0.31	0.30	−1.23
Asian/Pacific Islander	1.10	0.28	0.39
Hispanic	0.79	0.24	−0.77
Black	0.80	0.23	−0.80
Highest level of parental education	0.99	0.06	−0.24
Science useful in future (G8)	1.39	0.26	1.76
Expected career in STEM at age 30 (G8)	1.44*	0.26	2.04
G11 biology	2.69***	0.72	3.71
G11 chemistry	1.71**	0.27	3.38
G12 chemistry	1.49**	0.22	2.68
G12 calculus	1.51**	0.23	2.73
Mathematics IRT estimated numbers right (G12)	1.03**	0.01	2.76
Average grade—mathematics (G12)	1.03**	0.01	3.42
Interested in science (G12)	1.48***	0.10	6.14
Need science for college, job, or credit (G12)	1.10**	0.03	3.42
Listen to teacher lecture in science (G12)	0.82*	0.06	−2.50
Use books to show how to do experiment (G12)	0.88*	0.05	−2.01
Emphasis on further study in science (G12)	1.28**	0.11	3.03
Use computers in mathematics class (G12)	0.82*	0.08	−2.06
Use hands-on materials in mathematics (G12)	1.25**	0.11	2.60
How often pay attention in mathematics (G12)	1.27*	0.13	2.43

Note. $n = 1{,}860$ (population size = 361,400); $F(22, 629) = 9.45$, $p < .001$.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

experiments should be run were less likely to go on to a STEM degree whereas those who reported that further study in science was emphasized by their teachers were more likely to earn a degree in STEM.

In addition to the pedagogical variables, the Grade 12 survey asked students to report on reasons why they were enrolled in science and mathematics class. Students who reported that they frequently paid attention in mathematics class or that they needed to take science for future schooling or employment were more likely to go on to earn STEM degrees. Students were also asked questions about the influence various parties had on their decisions to enroll in 12th-grade science. Students who indicated that they were taking science based on a personal interest were significantly more likely to complete a major in STEM.

Planned Major. The next block of variables was used to assess factors that might be related to the field students' planned to select as a major once enrolled in college. In addition to all the variables retained from previous models, we thought it would be important to include summative variables for the total number of classes students completed in science, mathematics, engineering, and computer science as well as students' GPAs in mathematics and science and the highest academic level courses taken in these subjects. The results of this model (Table 6) indicate that the eighth-grade variable regarding usefulness of science continued to be strongly associated with earning a degree in STEM. In terms of courses,

TABLE 6
Summary of Logistic Regression Analysis Predicting Completion of a Degree in STEM: Planned Major

Predictors	Odds Ratio	*SE*	*t*
Female	0.97	0.11	−0.31
American Indian/Alaska Native	0.31	0.30	−1.20
Asian/Pacific Islander	1.34	0.26	1.47
Hispanic	0.95	0.19	−0.24
Black	0.71	0.20	−1.23
Highest level of parental education	1.06	0.05	1.26
Science useful in future (G8)	1.54**	0.21	3.19
Expected career in STEM at age 30 (G8)	1.34	0.22	1.78
G11 biology	2.32***	0.50	3.92
G11 chemistry	1.17	0.15	1.17
Mathematics IRT estimated numbers right (G12)	1.02**	0.01	2.62
G12 biology	1.36	0.23	1.79
G12 chemistry	1.51**	0.23	2.70
G12 physics	1.29	0.19	1.76
G12 trigonometry/Algebra II	1.37*	0.20	2.16
G12 calculus	1.41*	0.20	2.40
HS science average	1.02	0.01	1.33
Total HS science courses attempted	1.19*	0.08	2.48
Highest level of HS science	0.94	0.12	−0.51
HS mathematics average	1.04**	0.01	2.98
Total HS mathematics courses attempted	0.94	0.06	−0.97
Highest level of HS mathematics	0.99	0.21	−0.05
Planned major (G12)	4.22***	0.46	13.11

Note. $n = 3{,}940$ (population size = 800,420); $F(23, 810) = 20.98$, $p < .001$.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

11th-grade biology and 12th-grade chemistry, trigonometry, and calculus all had positive associations with earning a degree in STEM. From the summary variables, students with higher mathematics grades and those who enrolled in a higher number of science courses were more likely to complete degrees in STEM. In this model, the variable with the strongest relationship with a degree in STEM was the subject students planned to major in once they entered college. Students who in 12th grade indicated that they planned to major in a science or mathematics field were more than four times as likely to go on to complete degrees in STEM as their peers who planned to major in a non-STEM field.

College Variables. The final block of variables included in the analytical model deal with postsecondary experiences. In place of the grade-level course enrollment and performance variables (i.e., enrolled in ninth-grade algebra), we used summary variables created to indicate enrollment in specific mathematics and science courses (without timing included) as well as the number of courses attempted, academic level of courses, and average grades. Students' ratings of the usefulness of science and the total number of high school science courses attempted were positively associated with earning STEM degrees; however, enrollment in earth science and in precalculus had a negative relationship with that outcome.

Predictors for the final block include college enrollment and performance, significant life experiences (e.g., marriage, delay in college attendance), career intentions, and other variables shown by research to have a relationship with college completion or choice of major (Table 7). Similar to the final models produced by Adelman (2006), delay in postsecondary enrollment and student loans/work-study were not significant in their association with earning a degree in STEM. In regard to the development of family, getting married while enrolled in college had no significant effect on the outcome, but students who had children before completing a degree were significantly less likely to earn a degree in STEM. Assessing academic predictors, it appears students who completed higher numbers of STEM credits during their first year of college and those who had a stronger STEM-grade average

TABLE 7
Summary of Logistic Regression Analysis Predicting Completion of a Degree in STEM: Postsecondary Variables

Predictors	Odds Ratio	*SE*	*t*
Female	0.99	0.13	−0.06
American Indian/Alaska Native	0.60	0.59	−0.52
Asian/Pacific Islander	1.10	0.24	0.43
Hispanic	0.89	0.20	−0.50
Black	0.72	0.26	−0.91
Highest level of parental education	0.99	0.05	−0.20
Science useful in future (G8)	1.53*	0.25	2.58
Expected career in STEM at age 30 (G8)	1.31	0.23	1.51
Mathematics IRT estimated numbers right (G12)	1.01	0.01	1.01
HS biology	1.01	0.33	0.02
HS chemistry	0.87	0.20	−0.59
HS physics	0.83	0.13	−1.20
HS earth science	0.63**	0.10	−2.93
HS precalculus	0.72*	0.10	−2.30
HS calculus	0.96	0.14	−0.28
HS science average	0.99	0.01	−0.36
Total HS science courses attempted	1.35***	0.11	3.59
Highest level of HS science	0.87	0.12	−1.01
HS mathematics average	1.02	0.01	1.22
Total HS mathematics courses attempted	0.97	0.07	−0.37
Highest level of HS mathematics	1.05	0.26	0.20
Planned major (G12)	3.58***	0.51	9.02
Loans during PSE	0.99	0.14	−0.05
Work-study during PSE	1.10	0.19	0.56
Married before degree completed	1.30	0.22	1.53
Baby born before degree completed	0.37**	0.11	−3.31
Delay in PSE entry (months)	1.04	0.34	0.13
Total number of STEM courses at the general level	0.97	0.08	−0.43
GPA for all PSE STEM classes	1.36**	0.14	3.09
Number of failed STEM courses	0.59**	0.10	−3.10
STEM credits earned in first year of PSE	1.89***	0.10	11.96
Changed major (student report)	0.52***	0.08	−4.39

Note. $n = 3{,}600$ (population size = 733,170); $F(32, 786) = 15.88$, $p < .001$.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

TABLE 8
Summary of Logistic Regression Analysis Predicting Completion of a Degree in STEM: Final Model

Predictors	Odds Ratio	*SE*	*t*
Female	1.03	0.14	0.23
American Indian/Alaska Native	0.41	0.43	−0.86
Asian/Pacific Islander	1.01	0.19	0.07
Hispanic	0.68	0.15	−1.78
Black	0.63	0.20	−1.50
Highest level of parental education	0.95	0.04	−1.17
Science useful in future (G8)	1.33	0.26	1.46
Expected career in STEM at age 30 (G8)	1.44*	0.24	2.20
HS earth science	0.65**	0.10	−2.90
Total HS science courses attempted	1.18**	0.07	2.71
Planned major (G12)	3.32***	0.43	9.29
Baby born before degree completed	0.42**	0.11	−3.37
GPA for all PSE STEM classes	1.42***	0.12	3.96
Number of failed STEM courses	0.64**	0.09	−3.03
STEM credits earned in first year of PSE	1.88***	0.09	12.80
Changed major (student report)	0.53***	0.08	−4.47

Note. $n = 4{,}250$ (population size = 865,310); $F(16, 843) = 33.31$, $p < .001$.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

than their peers were both more likely to complete a degree in STEM. Students who failed more STEM courses in college and those who changed majors were less likely to earn a degree in STEM. Unfortunately, it is a limitation of the data set that more information regarding student experiences in postsecondary institutions was not collected.

Final Model. When the model is pared down to include only variables maintaining significance, it is evident that early indication of interest in STEM is associated with completion of a STEM degree. Table 8 reveals that students who in eighth grade indicated that they held an interest in a STEM career were significantly more likely to complete a STEM degree. While previous models indicated that enrollment in specific high school science and mathematics courses produced significant associations with completion of a STEM degree, in the final model only students who completed earth science in high school were less likely to earn a degree in STEM. Increased enrollment in science during high school had a positive association with a degree in STEM, but variables for performance and academic level of coursework lacked significance and were dropped from the model. The predictor in the model with the strongest positive relationship to a degree in STEM was based on student reports of the majors they planned to pursue in college. As might be expected, students who indicated that they planned to major in a STEM field in college were nearly three times more likely to complete a degree in that field than their peers who wanted to pursue degrees outside of STEM. Once in college, students who started off their schooling taking more STEM credits in their first year, and those who achieved higher grades in their STEM courses were more likely to complete degrees in STEM; those who had higher numbers of failed STEM classes and those who reported changing majors were less likely to complete degrees. Finally, students in the sample who had a child prior to completing a degree were significantly less likely to complete a STEM degree, than their peers.

Limitations of the NELS:88 Data Set

Before we continue, we wish to note the limitations of the NELS:88 data set. As discussed earlier, the base year of data collection was 1988, and the final follow-up of NELS:88 was completed in 2001. As is typical of large-scale data sets, much time is required to "clean" the survey data and enter it into a comprehensive data file. In addition, the data must be tested for inconsistencies, mistakes must be corrected, and the data characteristics must be weighted to produce the robust data set that is NELS:88. The time from completion of data collection to release of a cleaned and inspected data set is typically 3 years. Therefore, given that the version of NELS:88 analyzed in this study spanned from 1988 to 2001 and, given that it was first released in 2004, our examination here 5–6 years after its release is not unreasonable, and in fact, is fairly common (e.g., Murnane, Willett, & Tyler, 2000; You & Sharkey, 2009). While we agree that times have changed since 1988, we do not feel there is strong evidence to indicate that the way students react to their educational experiences and make enrollment or persistence decisions has changed in ways that would invalidate these findings.

DISCUSSION AND CONCLUSIONS

Although this analysis cannot establish causality, analysis of longitudinal data can identify the presence and absence of significant associations among many important factors related to persistence. The regression models demonstrated that neither race, gender, nor SES had a significant association with earning a degree in STEM. Although many fewer students from non-Asian minority groups completed majors in STEM, this finding suggests once in college the likelihood of students earning STEM degrees is equivalent, regardless of demographic background. While intuitively, it seems reasonable that both enrollment and achievement might be associated with earning a STEM degree, the final model found that only the number of science classes completed in high school was positively associated with a STEM degree, an indication that high school course enrollment in STEM classes may be an indicator of STEM-related persistence. Student interest and ratings of their abilities in mathematics and science, measured in different forms, played a significant and positive role in each model evaluated. Students who in eighth grade indicated that they were interested in a science career and those who believed science would be useful in their future were more likely to earn degrees in STEM. This finding complements other research (e.g., Tai et al., 2006; Simpkins, Davis-Kean, & Eccles, 2006) that shows the importance of early student interest and ability ratings in subsequent mathematics and science enrollment. Since, temporally these indications of interest come prior to their enrollment in high school courses, we believe that it is interest that drives enrollment, and not the reverse. However, this is definitely an area that requires more investigation in future research.

When asked in 12th grade about their plans for a college major, those who indicated a major in a STEM field were more than three times as likely to earn a STEM degree as those who were planning for a different major at that time. The significance of this factor indicates that the major students have in mind when leaving high school is a strong predictor of their eventual degree field, a finding supported by research on college freshman (Astin & Astin, 1993; Bonous-Harnmarth, 2000). While some students are turned on to STEM only when they reach college, our data point to the idea that many students make their major decisions before they ever arrive on college and university campuses. Therefore, future research needs to focus on delineating the factors related to students' precollege formal and informal STEM experiences and their relation to pipeline entry and persistence.

Once in college, students who changed majors, failed more classes, or had a child prior to completion of their degree were more likely to complete degrees in a non-STEM field. Students who started off college completing more STEM credits in their first year and those who earned stronger marks than their peers were more likely to go on to complete a STEM major. Another positive finding was that students involved in loan programs or work-study were no less likely to complete a degree in STEM, meaning that access to these fields is not restricted to those from advantaged financial situations.

Although certain classroom factors were found to be significant in predicting a degree in STEM, these variables could not be included in all analyses because of data limitations. The regression results provided confirmation of the positive relationship between markers of student interest and completing a major in STEM, but did not clearly identify all factors that account for the 82% of students who "switch" into the pipeline during high school—definitely an area where future research is needed.

A number of current policy initiatives could benefit from consideration of these results. A goal of *Race to the Top* funding is to increase the number of low-SES students completing rigorous (e.g., advanced placement) coursework in mathematics and science (Federal Register, 2010). Since the selected sample of NELS:88 students was limited to high school graduates who pursued substantial amounts of college coursework, we can only make statements about that group. For these students, it does not appear that requirements or inducements to get students to take more rigorous programs of mathematics and science coursework during high school leads to a large increase in the number of students pursuing STEM degrees. *No Child Left Behind* was designed to minimize achievement gaps and improve school accountability, but it included little discussion of improving student engagement or interest in school. The results of this study indicate that such a focus on proficiency will not necessarily yield an increase in the number of students pursuing science and mathematics beyond high school. While we agree with these initiatives, in principle, it seems that focusing attention on increasing student interest in science and mathematics and demonstrating to students the utility of these subjects in their current and future roles may pay greater dividends in building the STEM workforce.

What might this look like in practice? The most significant changes we recommend come in framing the presentation of material to make school mathematics and science more related to the daily lives of students. Make the science personal, local, and relevant. Rather than including chemical formulas for "classic" reactions or discussing the effects of sea-level rise on distant locales, focus the discussion on chemical processes in human digestion or an environmental analysis of a local stream. This approach shows students how science and mathematics are important in their lives and has been shown to increase engagement (Marks, 2000). Similarly, make learning active. Many science educators may misinterpret this as "do more labs." Instead, we mean to engage students through a mix of learning activities where students are actively investigating the world around them and thinking about how to solve science and mathematics problems. One way to accomplish both of these recommendations is through the inclusion of inquiry projects where students investigate real-world science problems that are relevant to them (e.g., Bouillion & Gomez, 2001; Rivet & Krajcik, 2007). Our data show that students reporting greater emphasis on these features in their science and mathematics classrooms report significantly higher levels of interest than their peers in classrooms where these features are not emphasized.

From this analysis and previous work, students' early career interests appear to be a significant factor in persistence (e.g., Tai et al., 2006; Cleaves, 2005). However, current research we are conducting with middle grades students indicates that they are not aware of career options or few indicate knowing professionals actively working in STEM fields. From this study, we see that there is a strong positive association between teachers emphasizing further study in science and discussing science careers and increased levels of student interest in science. What we recommend is more discussion within classrooms about the types of jobs available in STEM and whenever possible have students interface with local representatives of organizations in the science, engineering, and medical fields to raise career awareness.

While we did not directly test a structural model of SCCT, we believe our results provide supporting evidence for the interrelation between personal and environmental factors and behavior as proposed by Lent et al. (1994, 2000). With regard to personal factors, our models indicate that with a sample limited to college-bound students gender and race are nonsignificant. In addition, personal goals in the form of planned career (8th grade) or planned college major (12th grade) were strongly significant in predicting the students who complete STEM degrees. Conversely, our models did not provide statistical evidence that self-efficacy played a significant role in student persistence, despite work from others (Lent et al., 2008) suggesting that this factor is important in educational and career aspirations. There is also indication that classroom environment variables are significant in some of our intermediate models, yet these factors fall out of the final model. We plan to delineate more clearly the proximal and distal impacts of these environmental variables in future research. Another important environmental factor, SES—measured through parent's education level and involvement in loan programs and work-study—was nonsignificant in our models. While we cannot make direct causal claims about the impact of person and environment on academic and career behavior, our results point to this connection and the definite need for collecting richer data from a longitudinal sample to untangle these interactions.

The National Center for Education Statistics (NCES) recently began collecting data for their newest study, the High School Longitudinal Study. Although the study began in 2009 with surveying ninth graders, it is critical that this effort collects robust data on student interest and engagement in mathematics and science if we are to gain more resolution on the factors involved in student persistence in STEM. While we understand the difficulty in large-scale data collection, we recommend that future researchers collect multiple streams of data. The inclusion of classroom observations will allow researchers to triangulate between student and teacher surveys and observational data regarding pedagogical practices. This data stream could include classroom observations, as well as collection of course syllabi and student work. While translation of these data into quantitative values is not simple and requires some creativity, this step in the research is critical to develop a fuller picture of what is going on in classrooms and how those experiences may influence students. Also, adding questions asking students *why* and *how* as follow-ups is very important to the process of gaining a deeper understanding of the factors regarding students' attitudes and how students come to make critical life decisions.

In sum, policy makers and researchers interested in increasing the number of students pursuing STEM cannot continue to focus their attention solely on achievement and enrollment. Our findings support the logical basis of SCCT that there is a complex interplay of factors that are involved in student entry and persistence in STEM. Although it is much more difficult to quantify data on the constructs of "engagement" or "interest" in science and mathematics, large-scale efforts to understand these issues are critical to understanding how individuals persist in or leave from the STEM pipeline.

APPENDIX

TABLE A.1
Classification of Majors Into STEM and Non-STEM Fields

STEM Majors		Non-STEM Majors	
Code	Field	Code	Field
10	Agricultural business/production	40	Architect/environmental design
20	Agricultural/animal/plant science	50	American studies/civilization
30	Conservation/natural resources	51	Area studies
31	Forestry	53	Ethnic studies
110	Computer programming	60	Accounting
112	Computer science	61	Finance
140	Electrical/communication engineer	62	Operations research/administration science
141	Chemical engineering	63	Business administration/management
142	Civil engineering	65	HRD/labor relations
143	Mechanical engineering	69	Other business
144	Engineering: other	71	Other business support
149	Computer engineering	72	Medical office support
150	Engineering technical: nonelectrical	80	Marketing/distribution
170	Medical/veterinary laboratory technical/assistance	81	Retailing
171	Dental assistance/hygiene	87	Hospitality management
172	HPER	88	Real estate
174	Allied health: Other	90	Journalism
175	Physical therapy	91	Communications
176	Occupational therapy	92	Radio/TV/film
178	Other therapies	100	Communication technologies
180	Speech pathology/audiology	101	Information technologies
181	Clinical health science	111	Data/information management
185	Nursing	121	Other personal service
186	Health/hospital administration	130	Early childhood education
187	Public health	131	Elementary education
188	Other health science/profession	132	Secondary education
190	Nutrition/food science	133	Special education
262	Biochemistry	134	Physical education
263	Biological science: Other	135	Education: Other
271	Mathematics sciences/statistics	151	Engineering technical: Electrical/electronics
400	Chemistry	152	Computer technology
401	Geology/earth science	160	Foreign languages
402	Physics	191	Textiles/fashion

Continued

TABLE A.1
Continued

STEM Majors		Non-STEM Majors	
Code	Field	Code	Field
403	Physical science: Other	192	FCS & other human ecology
490	Air transport	200	Child study/guidance
		201	Culinary arts/food management
		220	Para-legal/prelaw
		221	Law
		230	English/American literature
		231	Writing: Creative/technique
		232	Letters: Other
		240	Liberal/general studies
		250	Library/archival science
		300	Women's studies
		301	Environment studies
		302	Biopsychology
		303	Integrated/general science
		304	Interdisciplinary humanities
		305	Social science: General
		306	Interior designing
		310	Recreation/sports
		380	Philosophy
		381	Religious studies
		390	Theology
		391	Bible studies
		420	Psychology
		421	Clinical/counseling psychology
		430	Administration of justice
		440	Social work
		441	Public administration
		442	Human/community service
		450	Anthropology/archaeology
		451	Economics
		452	Geography
		453	History
		454	Sociology
		455	Political science
		456	International relations
		480	Graphic/print communication
		500	Graphic/industrial designing
		501	Drama, speech
		502	Film arts
		503	Music
		504	Fine arts/art history
		505	FPA: Other
		900	Other

TABLE A.2
Demographics for Students Earning STEM Degrees by Three Different Measures

	College Transcript	Course Threshold	NSF (1996–1998)
Percentage of total bachelor's degrees	28.2	20.8	17.0
Male	50.6	51.6	62.9
Female	49.4	48.4	37.1
American Indian	0.0	0.0	0.5
Asian	8.5	8.3	11.2
Hispanic	4.6	4.7	6.0
Black	6.4	6.3	6.5
White	80.6	80.7	75.8
High school STEM average	86.2	86.1	NA
High school STEM courses	9.1	9.1	NA

This research was supported by a grant from the American Educational Research Association, which receives funds for its "AERA Grants Program" from the National Science Foundation and the National Center for Education Statistics of the Institute of Education Sciences (U.S. Department of Education) under NSF Grant #DRL-0634035. Opinions reflect those of the authors and do not necessarily reflect those of the granting agencies.

REFERENCES

Adelman, C. (2004a). The empirical curriculum: Changes in postsecondary course-taking, 1972–2000. Washington, DC: U.S. Department of Education.

Adelman, C. (2004b). Principal indicators of student academic histories in postsecondary education, 1972–2000. Washington, DC: U.S. Department of Education.

Adelman, C. (2006). The toolbox revisited: Paths to degree completion from high school through college. Washington, DC: U. S. Department of Education.

America COMPETES Reauthorization Act of 2010, H. R. 5116, 111th Congress, 2nd Session (2010).

Astin, A. W., & Astin, H. S. (1992). Undergraduate science education: The impact of different college environments on the educational pipeline in the sciences. Final Report. Los Angeles: Higher Education Research Institute.

Babad, E. (2001). Students' course selection: Differential considerations for first and last course. Research in Higher Education, 42(4), 469–492.

Babad, E., Darley, J. M., & Kaplowitz, H. (1999). Developmental aspects in students' course selection. Journal of Educational Psychology, 91(1), 157–168.

Bahrick, H. P., Hall, L. K., & Berger, S. A. (1996). Accuracy and distortion in memory for high school grades. Psychological Science, 7(5), 265–271.

Bonous-Harnmarth, M. (2000). Pathways to success: Affirming opportunities for science, mathematics, and engineering majors. Journal of Negro Education, 69(1/2), 92–111.

Bouillion, L. M., & Gomez, L. M. (2001). Connecting school and community with science learning: Real world problems and school-community partnerships as contextual scaffolds. Journal of Research in Science Teaching, 38(8), 878–898.

Bozick, R., & DeLuca, S. (2005). Better late than never? Delayed enrollment in the high school to college transition. Social Forces, 84(1) 531–554.

Bozick, R., & Ingels, S. J. (2007). Mathematics coursetaking and achievement at the end of high school: Evidence from the Education Longitudinal Study of 2002 (ELS:2002) (NCES 2008-319). Washington, DC: U.S. Department of Education, National Center for Education Statistics.

Burkam, D. T., & Lee, V. E. (2003). Mathematics, foreign language, and science coursetaking and the NELS:88 transcript data (NCES 2003-01). Washington, DC: U.S. Department of Education, National Center for Education Statistics.

Cleaves, A. (2005). The formation of science choices in secondary school. International Journal of Science Education, 27(4), 471–486.

Committee on Science, Engineering and Public Policy–National Research Council. (2005). Rising above the gathering storm: Energizing and employing America for a brighter economic future. Washington, DC: National Academies Press.

Davis-Kean, P. (2005). The influence of parent education and family income on child achievement: The indirect role of parental expectations and the home environment. Journal of Family Psychology, 19(2), 294–304.

Dean, C. (2008, January 16). Global advances challenge U.S. dominance in science. The New York Times, pp. A17.

DeBoer, G. (1984). Factors related to the decision of men and women to continue taking science courses in college. Journal of Research in Science Teaching, 21(3), 325–329.

DeBoer, G. (1986). Perceived science ability as a factor in the course selections of men and women in college. Journal of Research in Science Teaching, 23(4), 343–352.

European Commission. (2004). Europe needs more scientists: Increasing human resources for science and technology in Europe. Brussels: European Commission.

Federal Register. (2010, April 14). Overview information; Race to the top fund; Notice inviting applications for new awards for fiscal year (FY) 2010. Vol. 75(71) 8376. Retrieved May 1, 2010, from http://www2.ed.gov/legislation/FedRegister/announcements/2010-2/041410a.pdf.

Federman, M. (2007). State graduation requirements, high school course taking and choosing a technical college major. The B.E. Journal of Economic Analysis & Policy, 7(1), 32.

Fetters, W. B., Stowe, P. S., & Owings, J. A. (1984). Quality of responses of high school students to questionnaire items. Washington, DC: National Center for Education Statistics.

Gnoth, J., & Juric, B. (1996). Students' motivation to study introductory marketing. Educational Psychology, 16(4), 389–405.

Goyette, K., & Mullin, A. (2006). Who studies the arts and sciences? Social background and the choice and consequences of undergraduate field of study. Journal of Higher Education, 77(3), 497–538.

Haladyna, T., Olsen, R., & Shaughnessy, J. (1982). Relations of student, teacher, and learning environment variables to attitudes toward science. Science Education, 66(5), 671–687.

Haladyna, T., Olsen, R., & Shaughnessy, J. (1983). Correlates of class attitude toward science. Journal of Research in Science Teaching, 20(4), 311–324.

Hilton, T. L., & Lee, V. E. (1988). Student interest and persistence in science: Changes in the educational pipeline in the last decade. Journal of Higher Education, 59(5), 510–526.

Horn, L., & Kojaku, L. K. (2001). High school academic curriculum and the persistence path through college (NCES 2001-163). Washington, DC: U.S. Department of Education, National Center for Education Statistics.

Hosmer, D. W., & Lemeshow, S. (2000). Applied logistic regression (2nd ed.). New York: Wiley.

Ishitani, T. T. (2006). Studying attrition and degree completion behavior among first-generation college students in the United States. Journal of Higher Education, 77(5), 861–885.

Kidd, G., & Naylor, F. (1991). The predictive power of measured interests in tertiary course choice: The case of science. Australian Journal of Education, 35(3), 261–272.

Kopcha, T. J., & Sullivan, H. (2007). Self-presentation bias in surveys of teachers' educational technology practices. Educational Technology Research and Development, 55, 627–646.

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

Lacey, T. A., & Wright, B. (2009). Occupational employment projections to 2018. Monthly Labor Review, 132(11), 82–123.

Lent, R., Brown, S., & 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., Brown, S., & Hackett, G. (2000). Contextual supports and barriers to career choice: A social cognitive analysis. Journal of Counseling Psychology, 47(1), 36–49.

Lent, R. W., Sheu, H. B., 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.

Madigan, T. (1997). Science proficiency and course taking in high school: The relationship of science course-taking patterns to increases in science proficiency between 8th and 12th grades (NCES 97-838). Washington, DC: U.S. Department of Education, National Center for Education Statistics.

Maltese, A. V., & Tai, R. H. (2010). Eyeballs in the fridge: Sources of early interest in science. International Journal of Science Education, 32(5) 669–685.

Maple, S. A., & Stage, F. K. (1991). Influences on the choice of math/science major by gender and ethnicity. American Educational Research Journal, 28(1), 37–60.

Marks, H. M. (2000). Student engagement in instructional activity: Patterns in the elementary, middle, and high School Years. American Educational Research Journal, 37(1), 153–184.
Mau, W.-C. (2003). Factors that influence persistence in science and engineering career aspirations. Career Development Quarterly, 51(3), 234–243.
Munro, M., & Elsom, D. (2000). Choosing science at 16 (National Institute for Careers Education and Counseling Project Report). Cambridge, England: Careers Research and Advisory Center.
Murnane, R. Js., Willett, J. B., & Tyler, J. H. (2000). Who benefits from obtaining a GED? Evidence from high school and beyond. Review of Economics and Statistics, 82(1), 23–37.
Myers, R. E., & Fouts, J. T. (1992). A cluster analysis of high school science classroom environments and attitude toward science. Journal of Research in Science Teaching, 29(9), 929–937.
National Science Board. (2007, August 9). A national action plan for addressing the critical needs of the U.S. science, technology, engineering, and mathematics education system [Draft]. Arlington, VA: National Science Foundation.
National Science Foundation. (2010). Integrated postsecondary education data system completions survey [data file]. Retrieved December 1, 2010, from WebCASPAR: https://caspar.nsf.gov/.
Oakes, J. (1990). Opportunities, achievement, and choice: Women and minority students in science and mathematics. Review of Educational Research, 16, 153–222.
Obama, B. (2010, September 16). Remarks by the President at the Announcement of the "Change the Equation" Initiative. Copy of text downloaded December 1, 2010, from www.whitehouse.gov/the-press-office/2010/09/16/remarks-president-announcement-change-equation-initiative.
Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. International Journal of Science Education, 25(9), 1049–1079.
Pedhazur, E. (1997). Multiple regression in behavioral research (3rd ed.). Singapore: Wadsworth.
Piburn, M. D., & Baker, D. R. (1993). If I were the teacher: Qualitative study of attitude toward science. Science Education, 77(4), 393–406.
Rivet, A. E., & Krajcik, J. S. (2007). Contextualizing instruction: Leveraging students' prior knowledge and experiences to foster understanding of middle school science. Journal of Research in Science Teaching, 45(1), 79–100.
Robertson, I. J. (2000). Influences on choice of course made by university Year 1 bioscience students—A case study. International Journal of Science Education, 22(11), 1201–1218.
Rose, H., & Betts, J. R. (2001). Math matters : The links between high school curriculum, college graduation, and earnings. San Francisco: Public Policy Institute of California.
Schneider, B., Swanson, C. B., & Riegle-Crumb, C. (1998). Opportunities for learning: Course sequences and positional advantages. Social Psychology of Education, 2, 25–53.
Seymour, E., & Hewitt, N. M. (1997). Talking about leaving: Why undergraduates leave the sciences. Boulder, CO: Westview.
Simpkins, S. D., Davis-Kean, P. E., & Eccles, J. S. (2006). Math and science motivation: A longitudinal examination of the links between choices and beliefs. Developmental Psychology, 42(1), 70–83.
Sullins, E. S., Hernandez, D., & Fuller, C. (1995). Predicting who will major in a science discipline: Expectancy-value theory as part of an ecological model for studying academic communities. Journal of Research in Science Teaching, 32(1), 99–119.
Tai, R. T., Liu, C. Q., Maltese, A. V., & Fan, X. T. (2006, May 26). Planning early for careers in science. Science, 312(5777), 1143–1144.
Tinto, V. (1993). Leaving college: Rethinking the causes and cures of student attrition. Chicago: University of Chicago Press.
Trusty, J. (2002). Effects of High school course-taking and other variables on choice of science and mathematics college majors. Journal of Counseling and Development, 80, 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.
U.S. News & World Report (2008). America's best colleges 2008. Retrieved February 10, 2008, from http://colleges.usnews.rankingsandreviews.com/.
Van Langen, A., & Dekkers, H. (2005). Cross-national differences in participating in tertiary science, technology, engineering and mathematics education. Comparative Education, 41(3), 329–350.
Wang, J., & Staver, J. R. (2001). Examining relationships between factors of science education and student career aspirations. Journal of Educational Research, 94(5), 312–319.
Ware, N. C., & Lee, V. E. (1988). Sex differences in choice of college science majors. American Educational Research Journal, 25(4), 593–614.

Ware, N. C., Steckler, N. A., & Leserman, J. (1985). Undergraduate women: Who chooses a science major? Journal of Higher Education, 56(1), 73–84.

Weinburgh, M. (1995). Gender differences in student attitudes toward science: A meta-analysis of the literature from 1970 to 1991. Journal of Research in Science Teaching, 32(4), 387–398.

Woolnough, B. E. (1994). Effective science teaching. Philadelphia: Open University Press.

You, S., & Sharkey, J. (2009). Testing a developmental–ecological model of student engagement: A multilevel latent growth curve analysis. Educational Psychology, 29(6), 659–684.