Making the Connection: Timing of Taking Algebra in Secondary Schools and Future College STEM Participation

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Running Head: Time of Taking Algebra and College STEM Participation

Abstract

This study examined the connection between the timing of taking algebra in secondary schools and college STEM participation. Data for the study came from the National Education Longitudinal Study of 1988. Logistic and multinomial regression analyses were conducted where the outcome measures represented propensity of course enrolment and degree majors in STEM. Results suggested that while the timing of taking algebra has implications for mathematics and science course enrollment during the first two years' of college, its long term impact on degree attainment is complex. Depending on the subject matter, subtle patterns of relationships were observed among gender, ethnicity, the timing of taking algebra, and propensity in college course taking and degree attainment. Implications of these findings were discussed.

Making the Connection: Timing of Taking Algebra in Secondary Schools and Future College STEM Participation

Policymakers have a strong interest in reforming mathematics and science education because these subjects are seen as critical to economic competitiveness through their impact on innovation in scientific research and technology. Yet long-term trends in degree taking not only show a decline in student completion of natural sciences and engineering degrees compared to other countries, but point to the uneven participation in science and engineering in college across different demographic groups (see *Science and Engineering Indicators 2006*). Pre-college education, as the National Science Board (2006) emphasizes, is the foundation for fostering leadership in science, technology, engineering, and mathematics (STEM).

One important yet heatedly debated topic at the pre-college education level is on "the importance of preparing students for algebra and its role as a gateway course for later success in high school, college, and the workplace" (*Science*, 7 December 2007, p. 1534). Though "Algebra for everyone" is a familiar slogan in educational reforms concerning mathematics education (Edwards, 1990; Gamoran & Hannigan, 2000; Miner, 1995), the mandatory requirement recently adopted by the California State Board of Education that all 8th graders take algebra 1 test by year 2011 heightens a renewed interest in the subject among policy makers and politicians (Education Week, July 10, 2008).

Studies on early access to algebra indicated its positive effects on mathematics achievement in high school (e.g., Bozick and Ingels, 2007; Oaks and Guiton, 1995;

Smith, 1996). In addition, research on transition from high school to college in terms of taking introductory mathematics and science found that more advanced study of mathematics in high school was one of the two pillars supporting college science course performance (Sadler and Tai, 2007). Though research has provided elements for understanding the relationship between early access to algebra and advanced course work in high school mathematics and science, and some evidence of more advanced course work in high school mathematics for introductory college science, few empirical studies exist that investigate systematically the curricular pathways from secondary schooling into postsecondary education (Adelman, 2004).

Given that first year algebra is a gatekeeper course, it is important to examine the connection between students' timing of taking algebra in secondary schools and their postsecondary participation in STEM. Very few empirical studies exist, however, that examine carefully the connection between students' pre-college foundational preparation in algebra and their college participation in mathematics and science related majors. To strengthen the collaborative effort between K-12 and postsecondary institutions in designing interventions to increase STEM participation in college and workforce, policy makers need to know what and how different factors influence students' persistence and participation in STEM, with one key factor being the timing of taking algebra at the K-12 level.

Our study intends to examine the connection between students' timing of algebra in secondary schools and the likelihood of their college course participation and baccalaureate degree production in mathematics, natural sciences, and engineering. In particular, the study explores these issues for traditionally under-represented groups such as women and ethnic minority students.

Conceptual Framework and Prior Empirical Research

We drew several concepts from other scholars' research so as to provide a conceptual grounding for our empirical work on the connection between the timing of taking algebra in secondary schools and pathways into postsecondary STEM participation. The first concept we borrowed is based on Tinto's seminal work on college dropouts. Tinto (1987) suggested that institutions develop "early warning systems" that can spot and track students who may have difficulty completing college programs. In the case of students' "dropping out of" STEM majored fields, one of the early warning signals could be the timing of taking algebra in secondary schools. It is well known that high school mathematics is largely structured in a highly hierarchical and sequential manner (Bozick and Ingels, 2007), namely access to higher level mathematics courses (e.g., geometry and algebra 2) depends on successful completion of a prerequisite course (e.g., algebra 1). Because of this sequential feature of course taking patterns, the timing of taking the gatekeeper course, algebra, can be important for further participation in advanced mathematics and science in high school and beyond.

The second concept that inspired our thinking on the connection between the timing of taking algebra and postsecondary STEM participation, the concept of "path dependence", is rooted in studies from political science, sociology, and economics. The curricular pathways from secondary school into postsecondary education are both complex and conditioned by many factors (Adelman, 2004; US Department of Education, NCES, 2003). Borrowing the concept of path dependence from studies of political science (e.g., Pierson, 2000), sociology (e.g., Goldstone, 1998), and economics (e.g., Nelson and Winter, 1982), our study considers the timing of taking algebra in secondary schools as a critical juncture which could potentially set students off on different trajectories in terms of pathways into college STEM course participation and degree attainment. The concept of path dependence is a useful metaphor for thinking about developing "early warning systems" (Tinto, 1987) that spot and track students who may opt out of STEM fields, since today's choices constrain tomorrow's options. This path-dependent feature is especially true for attracting more students into STEM fields because more advanced mathematics and science studies are built on a solid foundation in these subjects at lower levels.

Besides the timing of taking algebra in secondary schools, other key factors affecting students' participation and persistence in math and science include students' demographic characteristics (e.g., gender, race/ethnicity) and various cognitive and social-psychological measures (e.g., mathematics ability, career aspirations, etc.). Long lines of research have documented extensively the relative low representation of women and minority students' participation in advanced math and science courses and STEM fields (e.g., Adelman, 1998). Researchers from different disciplines and with different perspectives have offered a variety of explanations for this disparity, ranging from cognitive (e.g., Clewell and Campbell, 2002), affective/psychological (e.g., Frost, Hyde, and Fennema, 1994), sociological (e.g., Fennema and Peterson, 1985), to economical status as proxies for opportunities to learn (e.g., Bozick and Ingels, 2007).

However, despite previous extensive research, it is not clear whether students' decisions to pursue further studies in STEM fields are a joint function of their demographic characteristics, social economic status (SES), and attitude towards STEM fields. For instance, it is possible that students from wealthier families might have wider career options than students from less privileged background. And some of the appealing or lucrative professional careers, such as lawyers, do not necessarily require a strong background in mathematics or science. Therefore, while students from higher SES overall tend to enroll in advanced mathematics and science courses more than those from lower SES (Bozick and Ingels, 2007), the SES could play a nuanced role depending on students' career aspirations.

Furthermore, depending on the specific STEM fields, the relationship between students' demographic characteristics and participation in these fields could be different. For instance, using the Beginning Postsecondary Student Longitudinal Study (BPS 96/98/01) data, Newton and Tao (2007) explored the relationship between gender, ethnicity, types of institutions (i.e., private vs. public), and baccalaureate degree production in natural sciences and engineering. They found that when comparing degree production in natural sciences versus engineering, females were more than two and a half times likely than males to have a major in natural sciences instead of engineering; in contrast, when comparing degree production in natural sciences vs. other disciplines (excluding engineering), females had close to one sixth of a chance as males to major in natural sciences instead of other disciplines. These preliminary analyses point to the complex and nuanced differences in outcomes for different STEM fields. In other words, patterns of participation among different demographic groups could be different depending on the specific STEM fields (e.g., biology vs. mathematics).

Taken together, these previous studies provide a foundation for studying the connection between students' timing of taking algebra during secondary school years and their postsecondary participation and persistence in mathematics and sciences, and for examining patterns of transitioning from secondary mathematics to college mathematics and sciences for underrepresented groups defined by gender, race or ethnicity, and social economic status.

Figure 1 describes the conceptual and analytical model connecting key elements of secondary school course taking and preparation (highlighting the timing of taking algebra), transition to college, and end of college degree attainment. The dotted lines imply uncertain paths. For instance, taking college introductory mathematics does not necessarily lead to a STEM major; instead, other factors might play a role such as whether completion of introductory mathematics leads to taking advanced mathematics; and whether other college experiences support persistence in STEM participation. One important point worth mentioning is that the conceptual and analytical model as represented in Figure 1 does not intend to imply a simplistic and linear relationship between pre-college preparation, transition to, and progress through college. Rather the framework is to highlight the key junctures of the pathway during important stages of a student's academic journey. In this study, we explored three key junctures specified as follows: (1) the timing of taking algebra in secondary schools, (2) course enrolment during first two years' of college, and (3) end of college degree attainment.

[Figure 1 about here]

Research Questions

The following questions guided our analysis for this paper:

1. What is the relationship between the timing of taking algebra in secondary schools and participation in college introductory mathematics and natural sciences courses?
2. What is the relationship between the timing of taking algebra in secondary schools and baccalaureate degree production in natural sciences and engineering?
3. What is relationship between the timing of taking algebra in secondary schools and college participation in sciences and engineering for traditionally underrepresented groups such as female and ethnic minority groups?

Method

Data Source and Study Sample

Data for our study came from the National Education Longitudinal Study of 1988 (NELS: 88). Sponsored by the U.S. Department of Education, National Center for Education Statistics (NCES), NELS: 88 followed a national sample of 25,000 8th graders in 1988 as they progressed through high school and postsecondary education (U.S. Department of Education, National Center for Education Statistics, 2003). Since 1988, the sample population of NELS: 88 respondents have been surveyed five times across 12 years. In addition to surveying the students, their parents or guardians (1988 and 1992), and their teachers and school administrators (1988, 1990, and 1992), the study also collected high school transcripts for the study participants in 1992, following the graduations of most of the students.

Our study utilized four waves of data, namely, (1) the baseline year, (2) the first follow up, (3) the second follow up when students were about in their second year of college studies, and (4) the fourth follow up which had students' degree major information. The sample size for our study varied depending on the outcome measures, ranging from 4,300 to 6,300 across different analyses. In all of our analyses, we used the NELS survey weights to weight the sample included in the analyses. The gender composition of the sample was 55% girls and 45% boys; whereas the ethnic groups were roughly 72% White, 12% Hispanic, 8% African American, 7% Asian/Pacific Islanders, and 1% Native Americans.

Variables

Apart from the outcome measures, our study included three types of explanatory variables, namely: (1) the timing of taking algebra, (2) demographic and social economic background, and (3) mathematics ability proxy measure and career aspirations. We included these key predictors because of their significant relationships with achievement, participation, and persistence in math and science based on existing empirical research studies. Detailed information on the variables is as follows.

Outcome Variables:

We focused on two outcome measures defined as follows: (1) Enrollment in college math and science courses: During the third follow up, the NELS:88 study asked students attending college whether they enrolled in non-remedial mathematics courses and in science courses such as physics, chemistry, or biology during the past two years. Students' responses to these questions were used as indicators of enrollment in non-remedial math or science courses during the first two years of college. In terms of enrollment in non-remedial mathematics courses, students were classified in two groups. One group consisted of students who reported taking only non-remedial math courses in college while the other group consisted of students who either declared taking remedial courses or declared not taking any mathematics courses. Students who reported attending both remedial and non-remedial courses were included in the remedial group

(2) STEM majors: Similarly, the NELS: 88 study asked students during the fourth follow up in which major they were enrolled; responses to this question were categorized into STEM and non-STEM majors. The STEM major categories included engineering, mathematics, physics, chemistry, and biology. However, when examining STEM majors, we separated out biology for the following reason: Compared to other STEM majors, biology requires the least amount of mathematics. Therefore, patterns of relationship between various predictors and majors could be different for biology and other STEM majors where there is a heavy demand for mathematics (e.g., engineering).

Predictor Variables:

The key predictors used in our models included the following variables: (1) Timing of taking algebra: During the base line year, students were asked whether they attended an algebra course or another advanced math course during that year. Additionally, students were asked whether they attended regular and/or remedial mathematics courses. During the first follow-up (i.e., when they were 10th graders), students were asked how much coursework they had done in algebra, geometry, and other math courses since the beginning of 9th grade. Based on students' responses, three groups were created: (1) group one consisted of students who reported taking only algebra or other advanced mathematics courses at the 8th grade (i.e., base line year); (2) group two consisted of students who reported attending algebra at the 9th grade; and (3) group three consisted of students who reported neither attending algebra at the 8th or the 9th grade. The last group (i.e., group three) was used as the reference group in the logistic analyses.

(2) Female: The sex composite variable from the NELS: 88 dataset was recoded into a female indicator variable, with males as the reference group.

(3) Ethnicity: The NELS: 88 dataset included a race composite with five major categories: Asian/Pacific Islander, Hispanic, African American, White, and Native American. Four ethnic dummy variables were created, indicating Asian/Pacific Islanders, Hispanic, African American, and Native American groups. In all logistic analyses, White was used as the reference group.

(4) Social economic status composite: This variable corresponds to the socioeconomic composite measure included in the baseline year of the NELS: 88 data. This is a continuous variable standardized with a mean of 0 and a standard deviation of 1.

(5) Mathematics ability proxy measure: This variable was based on the test results included in the NELS: 88 dataset. Specifically, the test results came from the baseline year (i.e., when students were 8th graders). The scores were originally standardized using t-scores with a mean of 50 and a standard deviation of 10. In order to make the regression coefficients more interpretable, we converted the t-scores into z-scores with a mean of 0 and a standard deviation of 1.

(6) Career expectations: This variable was based on students' self-report of career aspirations for working in science or engineering fields during the baseline year.

Statistical Analysis

The primary statistical technique we employed was logistic regression analysis for course participation, because the outcome measures were binary (i.e., the outcome measures take on values of "1" or "0"). Equation (1) shows a representation of a logistic regression model (Tabachnick and Fidell, 2001) for predicting the probability of a subject taking on a value of 1 (as opposed to 0) on a binary outcome with three predictors (i.e., X1 through X3):

$$(1) \boldsymbol{Y_i} = \frac{\boldsymbol{e}^{\boldsymbol{A}+\boldsymbol{B}1\boldsymbol{X}1+\boldsymbol{B}2\boldsymbol{X}2+\boldsymbol{B}3\boldsymbol{X}3}}{1+\boldsymbol{e}^{\boldsymbol{A}+\boldsymbol{B}1\boldsymbol{X}1+\boldsymbol{B}2\boldsymbol{X}2+\boldsymbol{B}3\boldsymbol{X}3}}$$

Where

Y_i is the estimated probability of subject *i* taking on a value of "1" on an outcome measure (e.g., having a major in engineering);

X's are predictors of interests (e.g., in our study, gender was one of the key predictors we examined)

Equation (1) can be expressed equivalently as equation (2) in logit form, which is the form with the most straightforward interpretation (Berk, 2004):

$$\textbf{(2)}\ \textbf{In}\left(\frac{\boldsymbol{Y}}{1-\boldsymbol{Y}}\right) = \mathbf{A} + \boldsymbol{B}1\boldsymbol{X}1 + \boldsymbol{B}2\boldsymbol{X}2 + \boldsymbol{B}3\boldsymbol{X}3$$

If both sides of equation (2) are exponentiated, the regression coefficient associated with each X becomes odds multiplier. Or put it in a different way, the coefficient of X1 shows the odds ratio for a one-unit increase in X1, holding constant X2 and X3. In our study, results are presented in the exponentiated format (see Table 1) and indicated odds ratios.

When examining patterns of STEM degree attainments, we utilized multinomial logistic regression analysis, since the outcome variable was coded as three categories: biology, STEM (excluding biology), and non-STEM majors. Multinomial logistic regression, which allows one to compare more than two groups, is a simple extension of logistic regression that compares only two groups. Results from multinomial regression analyses were also presented in the exponentiated format (see Tables 2 and 3). Strictly speaking, these exponentiated coefficients are referred to as RRR (relative risk ratios) in STATA; however, interpreting RRRs is much like interpreting odds ratios in a binary logistic regression.

Results

Propensity of Participation in Mathematics and Science Courses

Table 1 presents the logistic regression results for the models that focused on the enrollment in mathematics and sciences courses during the first two years of college. As mentioned earlier, the analysis focused on students' enrollment in four types of courses during the first two years of college, namely, mathematics, physics, chemistry, and biology. Each outcome (i.e., enrolment in the course) consists of two models. The first model included only the four race/ethnicity indicators, namely, Asian, Hispanic, African American, and Native American. This model compared propensity of course enrolment between these four ethnic groups and Whites, without taking into account other predictors. The second model added other key predictors in addition to the racial/ethnic dummy variables. As explained in the theoretical framework section, these additional key predictors included gender (coded 1 for female), students' social economic status, a proxy measure of students' mathematics ability, career aspiration for future work in science and engineering fields, and the timing of taking algebra (i.e., the gatekeeper course) in secondary schools.

The numbers in the table represented odds ratios while those in the parentheses were linearized standard error estimates.

[Table 1 About Here]

Patterns of course participation: ethnicity. Let's take a look at the numbers under model A for each of the four outcomes (from mathematics to biology, left to right). Three main patterns emerged in terms of participation in college mathematics and science courses among different ethnic groups. First, compared to Whites, Asians were close to 1.8 times (p <.01) more likely to enroll in physics and close to 1.7 (p <.01) times more likely to enroll in chemistry; however, they were equally likely to enroll in mathematics (odds ratio: 1.2) and biology (odds ratio: 1.1) courses as White. Second, Hispanic students were less likely than Whites to enroll in mathematics, physics, chemistry, and biology courses. Specifically, Hispanic students were about half as likely (odds ratios ranged from .50 to .59; all statistically significant at .01 level) as Whites to enroll in mathematics, physics, chemistry, and biology courses. Similarly, African American students were similarly less likely to enroll in physics (odds ratio: .48, p<.01) and mathematics (odds ratio: .73, marginally significant) than Whites, except for chemistry (odds ratio: .76, which was statistically not significant). In contrast, African American students were slightly more likely than Whites to enroll in biology courses (odds ratio: 1.3, marginally significant, *p*<.10). Finally, Native Americans were equally likely as Whites to enroll mathematics, physics, chemistry, and biology courses.

However, if we examine the numbers associated with the ethnic variables under model B for each of the four outcomes (i.e., when other critical predictors were added to the models), we noticed some important shifts in terms of course participation among different ethnic groups compared to Whites. As the results in Table 1 indicated, once we took into account other key predictors, Hispanic students were equally likely to enroll in mathematics (odds ratio: .83), physics (odds ratio: .96), and chemistry (odds ratio: .82) courses as Whites, other things being equal. Likewise, holding other predictors constant, African Americans were equally likely as Whites to enroll in mathematics (odds ratio: 1.09), physics (odds ratio: .77), and biology (odds ratio: 1.29) courses. Finally, Native American students were more likely than Whites to enroll in physics course (odds ratio: 3.43, *p* <.05), taking into consideration other predictors in the model.

Patterns of course participation: gender. Results in Table 1 suggested that other things being equal, females were equally likely as males to enroll in chemistry (odds ratio: .95). In contrast, females were about half times likely to enroll in physics courses as males (odds ratio: .49, *p*<.01), holding constant other predictors. And females were slightly less likely to enroll in regular college introductory mathematics course than males (odds ratio: .86, marginally significant, *p* <.10), other things being equal. But females were about twice likely as males to enroll in biology course (odds ratio: 2.01, *p*<.01).

Predictors of propensity for course participation: career aspirations and timing of taking algebra. As shown in Table 1, students' aspiration for work in science and engineering fields as early as grade 8 was a significant predictor of college propensity to enroll in mathematics, physics, and chemistry courses. Specifically, other things being equal, the higher the aspiration for science and engineering fields, the more likely one was to enroll in mathematics (odds ratio: 1.29 , p<.10), physics (odds ratio: 1.74 , p<.01), and chemistry courses (odds ratio: 1.89, p<.001). However, career aspiration for science and engineering fields was not significantly associated with the likelihood of biology course enrolment, holding constant other predictors (odds ratio: .91).

Apart from career aspirations, the timing of taking algebra also was a statistically significant predictor of college propensity in terms of course enrollment for mathematics, chemistry, and biology. Specifically, controlling for other critical predictors, students who took algebra earlier (i.e., at 8th or 9th grade) were more likely than those who did not (i.e., at 10th or later) to enroll in mathematics (odds ratio: 2.00 and 1.77 respectively, p <.01), chemistry (odds ratio: 2.11 and 1.83 respectively, p<.01), and biology courses (odds ratio: 1.65 and 1.89 respectively, p<.05 and p<.01 respectively). Interestingly, timing of taking algebra was not a significant predictor of course enrolment in physics course (odds ratio: 1.37 and 1.05 respectively), other things being equal.

Other predictors of course participation: social economic background and mathematics ability. Results in Table 1 suggested that else being equal, there were no statistically significant relationships between students' social economic background and college propensity to enroll in mathematics and science courses. In addition, we tested for possible non-linear relationship between social economic background and propensity to enroll in mathematics and science course and found no evidence for including a non-linear term in the model.

In contrast to social economic background, the proxy measure of students' mathematics ability was a statistically significant predictor of propensity to enroll in mathematics (odds ratio: 1.66, $p<.01$), physics (odds ratio: 1.86, $p<.01$), chemistry (odds ratio: 1.56, $p<.01$), and biology courses (odds ratio: 1.12, $p<.05$), everything else being equal. One point worth mentioning is that even though the proxy measure of student mathematics ability was a significant predictor of college participation in mathematics and science courses, the significant relationships between timing of taking algebra and propensity to enroll in mathematics, chemistry, and biology courses did not vanish even with the measure of mathematics ability in the model.

Propensity for Major in STEM Fields

Tables 2 and 3 present the multinomial logistic regression results for the models that examine the relationships between the same set of explanatory variables with STEM majors. Since biology and other STEM majors (i.e., mathematics, physical sciences including physics and chemistry, and engineering) exhibited different patterns of relationships with key predictors, we ran a multinomial logistic regression model that separated out biology as a category (Table 3) from other STEM majors (Table 2). The reference group in the multinomial logistic regression was non-STEM majors. Predictors were entered to the multinomial logistic model in four steps as follows: (1) ethnic variables, (2) gender (coded 1 for female) and social economic background, (3) mathematics ability and career aspiration for sciences and engineering fields, and (4) the timing of taking algebra. The four models listed in Tables 2 and 3 (from left to right) display the results from fitting the model for each of these four steps.

[Tables 2 and 3 About Here]

Patterns of STEM major participation: ethnicity. Results in Table 2 indicated one pattern in terms of STEM major participation among different ethnic groups compared to Whites. Specifically, if we only compared Asians, Hispanics, African Americans, and Native Americans with Whites respectively without taking into account anything else, Asians were about 1.6 times more likely than Whites to have STEM majors (odds ratio: 1.61 , p<.05). In contrast, Hispanic, African American, and Native American students were equally likely as Whites to have STEM majors. The patterns of participation in STEM majors remained the same among different ethnic groups compared to Whites as other important predictors were added to the model (see Table 2).

With respect to biology major (see Table 3), we observed two statistically significant differences. Specially, taking into account other key predictors, Asian students were about three times more likely than Whites to major in biology (odds ratio: 3.06, p<.01). There was also a significant difference between Hispanic and White (odds ratio: 1.82, p<.05), favoring Hispanic students. Results in Table 3 indicated that there was no statistically significant difference in propensity to major in biology between other ethnic group students (i.e., African American and Native American) and White students.

Patterns of STEM major participation: gender. Results in Table 2 indicated that everything else being equal, females were only about as one quarter times as likely to have STEM majors (excluding biology related majors) compared to males (odds ratio: .25, p<.01). However, the picture for biology looked quite different. Holding constant other predictors, females were equally likely as males to have a major in biology (odds ratio: 1.13).

Predictors of STEM major participation: career aspiration and timing of algebra. As shown in Table 2, other things being equal, the higher one's aspiration for careers in science and engineering, the more likely one has a major in STEM fields (odds ratio: 3.17, $p<.01$). Results in Table 3 also pointed to a statistically significant positive relationship between one's career aspiration and propensity of obtaining a biology major (odds ratio: 2.70, $p<.01$). Interestingly, Table 2 suggested that students who started algebra earlier (i.e., at 8th or 9th grade) were equally likely to have STEM majors as those who did not (odds ratio: 1.20 and .86 respectively), holding constant other predictors. In a similar manner, the timing of taking algebra was not a statistically significant predictor of biology major (see Table 3), other things being equal (odds ratio: 2.70 and 2.62 respectively).

Other predictors of STEM major participation: social economic background and mathematics ability. Results in Table 2 suggested that holding constant other predictors, students' social economic background was a marginally significant predictor of STEM majors (i.e., mathematics, physics, chemistry, and engineering, odds ratio: .82, $p<.10$). However, the propensity for majoring in biology was not statistically related to one's social economic background, other things being equal (odds ratio: 1.11; see Table 3).

In addition, results in Tables 2 and 3 also indicated that holding constant other predictors, the proxy measure of student mathematics ability was a statistically significant predicator of attainment of STEM majors (odds ratio: 2.06, $p<.01$), including biology major (odds ratio: 1.55, $p<.01$).

Summary of Results

In terms of patterns of participation among gender groups in college mathematics and science courses, we found that everything being equal, females were about equally likely as males to enroll in mathematics, chemistry, and biology courses; however, females were far less likely than males to enroll in physics courses. In terms of STEM majors, females were far less likely than males to major in mathematics, physical sciences (i.e., physics and chemistry), and engineering, but were equally likely as males to obtain biology major.

With respect to patterns of participation among different ethnic groups in college mathematics and science courses, we found that holding constant key predictors in our model, Asians were more likely than Whites to take physics and chemistry courses, but were equally likely as Whites to take college mathematics and biology courses. Similarly, African American students were equally likely as Whites to enroll in mathematics, physics, chemistry, and biology college courses. Hispanic students also were as likely as Whites to take mathematics, physics, and chemistry courses, but were less likely than Whites to enroll in biology course. Finally, Native Americans were as likely as Whites to take mathematics, chemistry and biology courses while more likely than Whites to enroll in physics course.

In terms of participation in STEM majors, Asians were more likely than Whites to major in all STEM fields (i.e., including biology). Hispanics, African Americans, and Native Americans were equally likely as Whites to major in mathematics, physical sciences (i.e., physics and chemistry), and engineering (i.e., non-biology STEM). In terms of propensity to major in biology, except for Hispanics, the other two ethnic groups (i.e., African American and Native American) were equally likely as Whites to major in biology.

In terms of predictors of college course participation, we found that two policy manipulable predictors were statistically significant. These included students' career aspiration for science and engineering fields and the timing of taking algebra (i.e., taking algebra at grade 8 or grade 9). One point worth mentioning is that these two variables were significantly related to the outcomes of interests (i.e., college course participation and STEM majors) even after controlling for the proxy measure of students' mathematics ability. In terms of predicting students' propensity to major in STEM fields, we found that students' career aspiration for science and engineering fields was a significant predictor, even after controlling for the proxy measure of students' mathematics ability.

Discussions

This study explored the connection between students' timing of taking algebra in secondary schools and their college STEM participation. In addition, the study examined several key factors affecting students' participation and persistence in mathematics and science, including students' demographic characteristics (e.g., gender, race/ethnicity) and various cognitive and social-psychological measures (e.g., mathematics ability, career aspirations, etc.). The study has generated several empirical findings on factors that are significantly associated with students' persistence and participation in college STEM.

To begin with, our study found that except for physics, the timing of taking algebra in secondary schools is significantly connected with the college propensity for enrollment in mathematics and science courses (i.e., chemistry and biology). In contrast, the timing of taking algebra is not a statistically significant factor when we constrain our attention to propensity for choosing STEM vs. non-STEM majors. These two findings point to the complex relationships between the time of taking algebra and future college STEM participation with respect to course taking and degree attainment. Though the timing of taking algebra has immediate implications for mathematics and science course enrollment during the first two years' of college, its direct long term impact on degree attainment is unclear and complex. This finding points to the need for further research on students' persistence in STEM as they transition from the lower division (i.e., typically the first two years of college) to the upper division (i.e., last couple of years of college).

Secondly, we found that students' career aspirations for science or engineering fields were significantly related to their college course enrolment and major in STEM fields. One point worth mentioning is that students' career aspirations were measured at grade 8. This finding points to the importance of early interventions in terms of deliberate efforts at encouraging students to aspire for future work in science, technology, and engineering. Mathematics-intensive fields are where significant gender and ethnic gaps exist (Clewell and Campbell, 2002). Therefore, our finding on how soon one can predict whether a student would be able to choose a math-intensive STEM major or not down the road based on this student's timing of taking algebra in secondary schools is an important signal. It points to the importance of early interventions and preparations so that students could succeed in the gatekeeper course and have adequate opportunities to be on a pathway towards high level mathematics and science studies.

Additionally, we found subtle patterns of college STEM participations among gender and different ethnic groups. With respect to the gender participation, females were about equally likely to enroll in mathematics and chemistry as males, and more likely than males to enroll in biology during the first two years' of college studies; however, they were far less likely to enroll in physics. By the end of college, though females were equally likely as males to major in biology, they were far less likely than males to major in non-biology STEM fields. Though our analyses do not provide clear answers to why this severe under-representation of females in non-biology STEM major exits, our finding provides a clue for possible interventions. Specifically, the low representation of females in physics courses during the first two years of college studies could be a warning signal for higher education institutions. Since fields such as engineering has a heavy demand for both physics and mathematics, strategies for increasing female students' interests and participation in physics courses early on could be one of the focus intervention areas.

In terms of patterns of participation in college STEM majors among different ethnic minority groups compared to Whites, our findings indicated that ethnic minority students for the most part were equally likely as Whites to participate in college STEM fields when we took into account critical factors such as career aspirations and academic preparation such as early access to algebra during secondary schools. The implication of this finding is that simple comparisons among different ethnic groups without additional information might not be helpful. In other words, simply knowing someone is African American, or Hispanic, for instance, does not tell us anything about his or her motivation and/or prior academic preparation. As our analyses suggest, African American and Hispanic students were equally likely to participate in college STEM fields when critical factors were taken into consideration (e.g., when they had similar career aspirations as Whites).

Finally, one of the central concerns among policy makers is to focus on traditionally underrepresented groups such as females and ethnic minority students. Our findings on subtle patterns of transition from secondary schools to college among gender and various demographic groups is helpful for policy conceptualization (e.g., to avoid one-size-fits-all policy initiatives). In addition, differentiating among specific STEM fields (e.g., math intensive fields such as mathematics, physics, chemistry, and engineering versus non-math intensive fields such as biology) when examining patterns of participation and persistence among different groups could also enhance our understanding and provide clues for further investigations.

To summarize, the empirical findings generated from this study have provided some clues on early factors (i.e., early warning signals) that bear important implications for later college STEM participations. These findings are useful for policy makers and other stakeholders (e.g., K-16 educators) as they attempt to strengthen the collaborative effort between K-12 and postsecondary institutions in designing intervention strategies for increasing STEM participation in college and workforce.

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Table 1: Enrollment in College Courses—Mathematics and Natural Sciences

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	T3_Math	T3_Math	T3_Phys	T3_Phys	T3_Chem	T3_Chem	T3_Bio	T3_Bio
	A	B	A	B	A	B	A	B
Female		0.857*		0.485***		0.947		2.010***
		(0.0690)		(0.0486)		(0.0922)		(0.164)
T0 Socioeconomic Composite		1.070		1.025		1.065		1.032
		(0.0681)		(0.0723)		(0.0700)		(0.0640)
T0 Mathematics Ability		1.661***		1.861***		1.556***		1.123**
		(0.0932)		(0.114)		(0.0839)		(0.0544)
T0_Algebra8		1.998***		1.369		2.114***		1.652**
		(0.383)		(0.367)		(0.501)		(0.375)
T1_Algebra9		1.765***		1.045		1.826***		1.894***
		(0.333)		(0.274)		(0.404)		(0.419)
T0 Expec. of Working in STEM		1.285*		1.743***		1.884***		0.907
		(0.195)		(0.255)		(0.236)		(0.108)
T0_Race==Asian/Pacific Islander	1.179	1.034	1.770***	1.735***	1.651***	1.378**	1.124	1.113
	(0.169)	(0.175)	(0.254)	(0.280)	(0.231)	(0.204)	(0.149)	(0.181)
T0_Race==Hispanic	0.586***	0.828	0.525***	0.963	0.498***	0.820	0.515***	0.559***
	(0.0766)	(0.138)	(0.0734)	(0.190)	(0.0627)	(0.134)	(0.0583)	(0.0846)
T0_Race==African American	0.728*	1.085	0.479***	0.769	0.760	1.369	1.315*	1.286
	(0.131)	(0.218)	(0.0795)	(0.172)	(0.138)	(0.283)	(0.217)	(0.229)
T0_Race==Native American	0.647	1.235	1.275	3.434**	0.696	1.304	0.768	1.026
	(0.235)	(0.446)	(0.549)	(1.962)	(0.385)	(0.708)	(0.306)	(0.441)
Observations	6326	4796	6335	4801	6336	4802	6335	4801

*** p<0.01, ** p<0.05, * p<0.1 (Numbers in parentheses are linearized standard error estimates.

Table 2: Majors in Mathematics, Sciences, and Engineering

VARIABLES	(1) T4_STEM	(2) T4_ STEM	(3) T4_ STEM	(4) T4_ STEM
Female		0.200***	0.220***	0.246***
		(0.030)	(0.033)	(0.038)
T0 Socioeconomic Composite		1.306***	0.875	0.823*
		(0.118)	(0.085)	(0.086)
T0 Mathematics Ability			2.114***	2.060***
			(0.159)	(0.187)
T0 Expec. of Working in STEM			3.092***	3.1743***
			(0.538)	(0.585)
T0_Algebra8				1.199
				(0.412)
T1_Algebra9				0.855
				(0.290)
T0_Race==Asian/Pacific Islander	1.607**	1.479*	1.422*	1.572**
	(0.325)	(0.315)	(0.293)	(0.332)
T0_Race==Hispanic	0.931	1.076	1.689*	1.611
	(0.252)	(0.276)	(0.494)	(0.598)
T0_Race==African American	0.676	0.896	1.45	1.695
	(0.192)	(0.278)	(0.446)	(0.550)
T0_Race==Native American	0.705	1.137	1.757	2.076
	(0.541)	(0.859)	(1.533)	(1.944)
Observations	5362	5362	5097	4296

*** p<0.01, ** p<0.05, * p<0.1 (Numbers in parentheses are linearized standard error estimates.)

Table 3: Major in Biology

VARIABLES	(1) T4_Biology	(2) T4_ Biology	(3) T4_ Biology	(4) T4_ Biology
Female		1.031	1.123	1.131
		(0.15)	(0.162)	(0.180)
T0 Socioeconomic Composite		1.597***	1.169	1.11
		(0.172)	(0.15)	(0.152)
T0 Mathematics Ability			1.665***	1.548***
			(0.164)	(0.174)
T0 Expec. of Working in STEM			2.745***	2.699***
			(0.597)	(0.604)
T0_Algebra8				2.702
				(1.491)
T1_Algebra9				2.623
				(1.450)
T0_Race==Asian/Pacific Islander	3.287***	3.151***	2.991***	3.063***
	(0.658)	(0.626)	(0.639)	(0.678)
T0_Race==Hispanic	1.278	1.671**	2.022***	1.822**
	(0.275)	(0.38)	(0.499)	(0.456)
T0_Race==African American	0.638	0.808	1.144	1.023
	(0.192)	(0.25)	(0.346)	(0.350)
T0_Race==Native American	0.994	1.219	1.587	1.786
	(0.675)	(0.829)	(1.069)	(1.311)
Observations	5362	5362	5097	4296

*** p<0.01, ** p<0.05, * p<0.1 (Numbers in parentheses are linearized standard error estimates.)

Figure 1

Conceptual and Analytical Model of Connecting High School Mathematics Course Taking and Pathways into Postsecondary STEM Fields