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Math coursetaking trajectories in high school during the COVID-19 disruptions to schooling

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Using student-level transcript data and information about instructional mode among public high school students in Massachusetts, this study examines the impact of disruptions to in-person instruction during the COVID-19 pandemic on students' math coursetaking trajectories. We find that rates of advancement (that is, of taking a higher-level math course in one year compared to the prior year) decreased during the 2020-21 school year—especially among students who spent a greater share of the year in remote instruction. Findings also reveal widening race-based and socioeconomic gaps in math advancement at higher levels of remote instruction. These disruptions contribute to stratification in two ways: students who do not advance in one grade level are less likely to attain higher levels of math in high school generally, and the variation in disruption by race and socioeconomic status means some students fell even further behind in subsequent grades.

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MATH COURSETAKING TRAJECTORIES IN HIGH SCHOOL DURING THE COVID-19 DISRUPTIONS TO SCHOOLING

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Abstract

Using student-level transcript data and information about instructional mode among public high school students in Massachusetts, this study examines the impact of disruptions to in-person instruction during the COVID-19 pandemic on students' math coursetaking trajectories. We find that rates of advancement (that is, of taking a higher-level math course in one year compared to the prior year) decreased during the 2020-21 school year—especially among students who spent a greater share of the year in remote instruction. Findings also reveal widening race-based and socioeconomic gaps in math advancement at higher levels of remote instruction. These disruptions contribute to stratification in two ways: students who do not advance in one grade level are less likely to attain higher levels of math in high school generally, and the variation in disruption by race and socioeconomic status means some students fell even further behind in subsequent grades.

Keywords: Educational trajectories; mathematics; high school; transcript data; COVID-19

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MATH COURSETAKING TRAJECTORIES IN HIGH SCHOOL DURING THE COVID-19 DISRUPTIONS TO SCHOOLING

Introduction

Policymakers, journalists, and researchers are sounding the alarm about a crisis in math achievement and skills among middle and high school students in the United States. Eighth and twelfth graders posted some of their lowest scores on the latest National Assessment of Educational Progress math tests—dubbed the "Nation's Report Card"—since the early 2000s (NAEP 2024), continuing a slide that began at least a decade ago (Wyckoff 2025). About 39% of 8th graders and 45% of 12th graders scored below basic in math (NAEP 2024). Eighth graders in the U.S. rank 22nd in the world in math achievement (von Davier et al. 2024). While students' reading test scores have not been spared, the declines in math have been particularly dramatic, and math is more tightly connected to future success in school and at work (Gilreath et al. 2023; Williamson 2025). This crisis has many long-standing and more recent causes, including the rigidity with which students progress through different levels of math, a shrinking supply of qualified math teachers, lowered expectations for students, reductions in school funding, and students' increasing use of smartphones and social media (CRPE 2025; Wyckoff 2025).

Although these trends predate COVID-19, the educational, economic, and social disruptions wrought by the pandemic have hastened the crisis. Much research has demonstrated the deep and lasting toll taken on students and their education by the COVID-19 pandemic. Students experienced substantial learning loss (Engzell et al. 2021), lower test scores in math and reading (Cohodes et al. 2022; Fahle et al. 2024), and lower rates of high school completion (Liu 2023) and enrollment in college or university (Denice and Andersen 2025; Harris et al. 2024). Low-income students, students of color, and those who attended high-poverty schools experienced particularly high rates of unfinished learning and test score decline (Peters et al. 2023). These effects were at least partly due to the move by many schools and districts to virtual or remote instruction (Landivar et al. 2022; Jack et al. 2023). Virtual schooling is associated with heightened isolation and lower engagement, which undermine students' academic achievement and attainment (Domina et al. 2021). Further, online learning made access to reliable internet, computers, and other digital resources essential for education (Frenette et al. 2020; Lai and Widmar 2021), opening the door for socioeconomic and race-based disparities in learning loss (Chetty et al. 2020; von Hippel 2020; Malkus 2020).

Less is known, however, about how the pandemic affected students' math attainment, particularly as they progressed through high school (Kuhfeld et al. 2025). Examining the relationship between disruptions like the pandemic and students' math trajectories is important for several reasons. First, tracking is particularly apparent in math. Math course titles have a clear and largely consistent sequencing (Domina and Saldana 2012), and moving up that hierarchy is predicated on having attained the requisite knowledge from a prior level (Han et al. 2023). In most middle and high schools in the U.S., students progress from general math to Algebra I, geometry, and Algebra II, before taking more advanced courses such as statistics, trigonometry, pre-calculus, and calculus (Loveless 2021). Failing to advance and getting off-track in early grades can limit how far up the math attainment ladder a student can ultimately go. Second, students' coursetaking trajectories in math can provide a window into their learning opportunities and outcomes as well as inequalities therein (Kuhfeld et al. 2025). Math coursetaking reflects the extent to which students feel supported and have the resources and opportunities at their school to attain higher levels of math as well as the degree to which they feel prepared for college and career beyond high school. Third, math coursetaking is consequential. Students' highest math course in high school is a key predictor of postsecondary enrollment, college degree completion, and labor market outcomes (Adelman 2006; Rose and Betts 2004).

In this article, we draw on administrative transcript data from Massachusetts public high school students to examine how the COVID-19 pandemic and the shift to remote instruction influenced high school students' advancement in math courses. More specifically, we address three research questions: (1) How are student and school characteristics related to the amount of time during the 2020-21 school year that students spent in remote instruction? (2) Were students less likely to complete a higher level math course in one grade than they did in the prior grade during the pandemic, and was this especially the case among students who spent more time in remote instruction? (3) Did the relationship between the shift to virtual learning during the pandemic and students' math advancement vary by economic (dis)advantage or race/ethnicity?

Background

Math Achievement and Attainment

We focus on mathematics coursetaking in high school for three main reasons. First, high school math, more than English or even science, is hierarchically structured in that courses follow readily identifiable tracks and prescribed sequences (Adelman 2006; Ogut and Circi 2023; Tyson and Roksa 2016). Mathematical skills and concepts build upon one another as students make their way through the sequence, which in turns means that the knowledge from one class must generally be mastered before students can successfully move on to the next course in the sequence (Riegle-Crumb 2006). The normative or typically recommended progression in the U.S. for college-bound high school students is to begin in Algebra I, which then opens up the opportunity to take geometry in grade 10, Algebra II in grade 11, and precalculus or another advanced math course like statistics in grade 12 (National Mathematics Advisory Panel 2008; Common Core State Standards 2023). This borne out by the data: many students nationwide begin in Algebra I and progress subsequently to Geometry and then Algebra II (Han et al. 2023; Ogut and Circi 2023). The high school math curriculum in Massachusetts is similarly organized around the progression from Algebra I to Algebra II or more advanced courses across four years of math coursework in grades 9 through 12 (DESE 2017).

The sequential nature of math and its escalating prerequisites create a positional advantage for those students who begin high school in courses higher up in the hierarchy (Schneider et al. 1997). In other words, where students begin is strongly linked to how far they can expect to go by the time they leave high school (Lucas 1999). MA's mathematics curriculum framework, for instance, notes that students who want to complete calculus by the end of high school need to enter the 9$^{\text{th}}$ grade having already taken Algebra I in middle school or they will need to follow a compacted or accelerated pathway in high school (DESE 2017). At the same time, taking a higher-level math course in grade 9 is a necessary but not sufficient condition for reaching advanced level coursework by grade 12 (Riegle-Crumb 2006). Prior research has uncovered a large degree of heterogeneity and churn among math coursetaking trajectories, with many students diverging from the normative structure of high school math, even when they start at similar levels (Han et al. 2023; Irizarry 2021; Ogut and Circi 2023; Schiller and Hunt 2011).

Second, high school math coursetaking is an important site of inequality in education. The hierarchical organization of high school math courses means that only those students who have demonstrated sustained success—that is, who have consistently mastered the curricula at each successive stage and who have met educators' expectations over a long period of time, beginning before students even enter the 9$^{\text{th}}$ grade—are given the opportunity to take advanced math courses such as calculus (Riegle-Crumb and Grodsky 2010; Hirschl and Smith 2023). In other words, math coursetaking is cumulative and path dependent, such that gaps in middle school and early high school grades compound as students progress through their education. This is particularly true for Black and Hispanic students and those from less socioeconomically advantaged backgrounds (Irizarry 2021; Hirschl and Smith 2023; Thompson 2017).

Students from more advantaged backgrounds—such as having college-educated parents or based on composite measures that incorporate parents' education, occupational prestige, and family income—are more likely to enroll in advanced math coursework (Crosnoe and

Muller 2014) and accumulate more math credits in high school (Crosnoe and Schneider 2010). And although Black and Hispanic students have increased their representation in advanced math courses, they continue to lag behind their White and Asian counterparts. Nationally, in 2019, 48% of Asian/Pacific Islander, 22% of White, 14% of Hispanic, and 11% of Black students reached calculus by the end of high school (Loveless 2021).[1]

Importantly, preexisting differences in academic preparation do not fully explain race– or socioeconomic-based gaps in advanced math courses (Dondero and Muller 2012; Flores 2007; Irizarry 2021; Kelly 2009; Souto-Maior and Shroff 2024). Such gaps in advanced math coursetaking persist even when districts attempt to loosen the rigidity of tracking in math and equalize opportunities for students entering high school (Huffaker et al. 2025; Weis et al. 2015). Further, not all students benefit from taking higher level math courses in the same way. For instance, the gap in 12^{th} grade standardized math test scores between White students and Black and Hispanic students is largest among those students who take the highest-level math classes, such as pre-calculus and calculus (Riegle-Crumb and Grodsky 2010). And while the sequential nature of mathematics suggests that where one starts matters for where they end up, this is not equally the case for all students. Less socioeconomically advantaged as well as Black and Hispanic students are less likely to follow normative math course sequences in high school as compared to their more advantaged or White counterparts (Schiller and Hunt 2011; Irizarry 2021; Han et al. 2023). Similarly, Riegle-Crumb (2006) finds that Black and Hispanic males receive lower returns from taking Algebra I in grade 9 compared to White males, reaching lower levels of the math hierarchy even when they begin in the same position.

By contrast, the gender gap in advanced math coursetaking in high school has narrowed and even reversed in recent decades (Buchmann et al. 2025; Riegle-Crumb 2006). In 2019, equal shares of men and women (16%) completed calculus as their highest-level math course, but a higher share of women (44%) than men (38%) left high school having completed

[1] At the time of writing, 2019 is the latest available nationally-representative data and corresponds to the pre-COVID comparison year in our data.

precalculus, statistics or trigonometry as their highest course (Buchmann et al. 2025). At the same time, women's advantage in high school math coursetaking does not protect them from leaks further down the pipeline; they are less likely to major in STEM fields once they get to college (Morgan et al. 2013).

Third, math coursetaking in high school is consequential for a variety of life outcomes. Advanced math courses provide students with opportunities to complete cognitively demanding work, interact with high-achieving teachers and classmates, and earn advantageous credentials on their transcripts, all of which translate to long-term educational and occupational benefits (Riegle-Crumb 2006). Students are more likely to attend four-year institutions and choose STEM majors (Han et al. 2023; Long et al. 2012), to complete college (Adelman 2006), and have higher incomes (Joensen and Nielsen 2009; Rose and Betts 2004) when they take higher level math courses, particularly precalculus or calculus. One analysis of NLSY97 data shows that high school graduates with low levels of math attainment (i.e., those who completed Algebra I or below) are 50% more likely to be unemployed and earn $1.30 less per hour than those with higher math attainment (i.e., those who completed at least geometry) (James 2013). Exposure to more advanced math coursework has also been shown to narrow the racial/ethnic and socioeconomic earnings gaps after high school (Goodman 2019; Rose and Betts 2004).

Education During the Pandemic

The COVID-19 pandemic proved extremely disruptive to education, compromising students' learning and widening gaps by race/ethnicity and socioeconomic status (Engzell et al. 2021; Gee et al. 2023; Goldhaber et al. 2023; Singer 2025a). A large part of these educational consequences stems from the rapid move to remote or virtual instruction. Widespread school closures shortly after the pandemic was declared in March 2020 affected an estimated 95% of the global student population (Betthäuser et al. 2023). In addition to the stress of living through a pandemic, the shift to remote instruction was associated with reduced physical health and mental wellbeing among young people (Viner et al. 2022) and dampened students' engagement and self-efficacy (Ober et al. 2023). Students are less engaged and learn less online than in in-person settings (Xu and Jaggars 2013), and the speed at which educators and students had to transition to remote and hybrid instruction necessarily impacted the content of what students learned in addition to the mode of instruction (Ober et al. 2023). Students who spent more time in virtual schooling experienced more learning loss (Goldhaber et al. 2023). One study concludes that students' learning losses during the pandemic's school closures were as large as they would have been had no teaching occurred at all (Engzell et al. 2021). Learning losses were apparent across subjects, but were largest in mathematics (Wisenöcker et al. 2025).

In addition, much evidence highlights the pandemic's disproportionate toll on the learning of Black and Hispanic students, as well as those from lower socioeconomic backgrounds. For instance, research finds that math and reading test score gains during 2020-21 were lower among Black and Hispanic students compared to White and Asian students (Kuhfeld et al. 2022), and that remote and hybrid instruction played a primary role in widening gaps in achievement by race and school poverty (Goldhaber et al. 2023). Beyond test scores, Black, Hispanic, and lower-income students also had higher rates of and larger increases in absenteeism, course failure, and grade retention (Evans et al. 2024; Fuller et al. 2022). More time spent in virtual or hybrid learning in 2020-21 also increased the within-school gap in high school completion rates between economically disadvantaged and non-disadvantaged students (Liu 2023).

There are several reasons for these widening racial/ethnic and socioeconomic gaps. Exposure to the COVID-19 virus as well as rates of infection and death varied by race/ethnicity and socioeconomic status (Wrigley-Field et al. 2020; Yancy 2020), which meant that Black, Hispanic, and lower-income children missed more school due to illness and quarantines (McNeely et al. 2023). Additionally, longstanding structural barriers like housing instability and lack of access to reliable transportation were exacerbated by the pandemic (McNeely et al.

2023). Relatedly, the shift to remote learning was concentrated among schools and districts with higher shares of non-White and lower-income students (Goldhaber et al. 2023; Singer 2025b). Remote learning necessitated reliable access to high-speed Internet and Internet-enabled devices (Domina et al. 2021), and such access is patterned along racial/ethnic and socioeconomic lines (Bailey et al. 2021; Francis and Weller 2022). Further, the loss of a socially diverse group of peers, as schools provide in face-to-face settings, was particularly detrimental to lower-income students (Agostinelli et al. 2022).

The Present Study

In sum, understanding whether high school students advance through the hierarchical mathematics sequence provides a useful window into the resources and opportunities available to students in schools, highlights race-based and socioeconomic inequalities in educational opportunities and outcomes, and sets the stage for future potential educational and labor market outcomes. And while much has been written about the negative impacts of the COVID-19 pandemic on a host of educational outcomes including math and reading test scores, absenteeism, high school completion, and postsecondary enrollment, comparatively less has focused on the pandemic's consequences for high school math attainment. In this study, we build on an important exception in a few ways. Kuhfeld et al. (2025) draw on test score data from nearly 2 million students nationwide to assess the relationship between the COVID-19 pandemic and students' math coursetaking trajectories. They find only small and statistically non-significant differences in enrollment rates in Algebra I, Geometry, and Algebra II between 9^{th} grade students pre-COVID and during the pandemic, though there were significant negative differences among 10^{th} grade students.[2] We build on this work and the research on COVID-19's impact on educational outcomes more generally in a few ways.

First, we leverage full transcript data from public high school students who transitioned

[2] Kuhfeld and colleagues (2025) base their measure of course enrollment on the specific standardized math test students took, which they validate against actual course roster data; they find that 70-80% of students who took a course-specific test were included in the roster with a course name consistent with their test type.

from grade 9 to 10 and from grade 10 to 11 between 2017-18 and 2020-21. Transcript data means we have clear and consistent information about the courses in which students enrolled, as well as whether they successfully passed those courses. Our observation window allows us to compare students before (2017-18 and 2018-19) and during (2019-20 and 2020-21) the pandemic. Second, we incorporate a measure of the proportion of the 2020-21 school year students spent in remote instruction. This permits us to describe not only the overall association between math coursetaking and COVID-19 but also the degree to which remote instruction during the pandemic is related to students' math coursetaking. Unlike prior studies of the educational impacts of COVID-19 that have relied on district- or school-level measures of virtual or hybrid learning (e.g., Goldhaber et al. 2023; Jack and Oster 2023; Liu 2023), we capitalize on a student-level measure based on the share of school days that they spent in remote instruction. This is useful because remote instruction could vary within districts or schools. Particularly in districts and schools that provided hybrid (as opposed to fully remote) instruction, it is possible that some students stayed in virtual learning longer than some of their schoolmates (Singer 2025a). Indeed, in our data, a substantial portion (about 71%) of the total variation in the proportion of the 2020-21 school year spent in remote instruction occurs *within* districts. Third, we examine variation in the relationship between math coursetaking and remote instruction by both race/ethnicity and socioeconomic status.

Data and Methods

We draw primarily on two administrative, student-level datasets provided by the MA Department of Elementary and Secondary Education (DESE). First, the Student Information Management System (SIMS) includes consistent student identifiers across years and schools, as well as individual demographic information. Second, Student Course Schedule (SCS) data provides information from academic transcripts that contain each course a student took as well as their course completion and performance. We also incorporate Massachusetts

Comprehensive Assessment System (MCAS) data, which provides students' standardized test scores, and school-level data from the National Center for Education Statistics' Common Core of Data and the Urban Institute's Model Estimates of Poverty in Schools (Urban Institute 2023).

We observe the population of students who were in grade 9 or 10 in the 2016-17 through 2019-20 school years, and who transitioned into grades 10 and 11 in 2017-18 through 2020-21. We focus on the transitions from 9^{th} to 10^{th} grade and from 10^{th} to 11^{th} grade because these earlier grades reflect students' transition to high school and because the decisions students make earlier in high school are the most critical in determining their overall, end-of-high-school math attainment (Frank et al. 2008; Kuhfeld et al. 2025). We further restrict our sample to those students who did not skip or repeat a grade in high school (Han et al. 2023) and who were not missing transcript or school-level information. Table A1 in the appendix provides full details about our sample restrictions. Our data consist of 327,567 unique students and 514,787 student-year records.

Measures

Advancement in Mathematics

Our primary outcome variable is a binary indicator representing whether a student *advanced in math* between one grade level and the next (Frank et al. 2008). To construct this measure, we first set up a hierarchical sequence of math course categories. This helps mitigate some of the variation in course names and content across and even within districts in the SCS transcript data. We use course names and descriptions to match each detailed math course to the following broader set of ordered categories: (0) No math; (1) Basic or other math; (2) Algebra I; (3) Geometry; (4) Algebra II; (5) Advanced math; (6) Pre-calculus; (7) Calculus (see Table A2 in the appendix for examples of detailed courses in each broad category).[3] These categories capture course content and reflect the typical progression in difficulty—from less to more advanced (Han et al. 2023; Ogut and Circi 2023; Frank et al. 2008). Because the transcript data includes courses from different divisions of the academic year (e.g., some courses are a full year, while others take place over a semester or quarter), we standardize course-taking by selecting a student's highest level of math coursework in a given grade level. We define coursetaking as enrolling in and successfully passing a course. When a student did not attempt or pass a math course in a given grade level, they are assigned a value of "No math." The variable measuring advancement equals 1 if a student's math level increased from one grade to the next (i.e., from grade 9 to 10, or from grade 10 to 11), and 0 if their math level stayed the same or decreased.

Additional Indicators of Mathematics Attainment and Achievement

We also describe patterns in other measures of mathematics attainment and achievement. In addition to advancement in math, we use our 7-category hierarchical math categories to examine the share of students who, from one grade level to the next, step down in the level of coursework difficulty, take a course at the same level, or take no math course. Together, these provide a fuller picture of students' *relative curricular attainment* than advancement alone (Han et al. 2023).

Furthermore, we assess students' *absolute curricular attainment*. In descriptive analyses, we allocate students' current math course (that is, in grade 10 or 11) into one of three categories: (1) Low; (2) Conventional; and (3) High. These summarize students' math attainment trajectories thus far since their current math course reflects their successful prior completion of lower level math courses. We define these categories based on prototypical

[3] In sensitivity analyses, we assigned each math course to a set of 14 more detailed categories: (0) No math; (1) Basic math; (2) Other math; (3) Pre-algebra; (4) Algebra I; (5) Geometry; (6) Algebra II; (7) Trigonometry; (8) Other advanced math; (9) Probability and statistics; (10) Other AP math; (11) Pre-calculus (including AP); (12) Calculus; (13) AP calculus. The results are substantively similar, in part because students typically take one course at a given level (e.g., a student will generally take either Calculus or AP Calculus). Further, we find no evidence that the rate at which 10^{th} or 11^{th} grade students took AP courses varied over time or by remote instruction.

pathways found by prior research (Han et al. 2023; Ogut and Circi 2023) as well as the distribution of students across math courses in our data. For instance, geometry is the modal level of math course among grade 10 students in our sample. The 52% of grade 10 students who took geometry are thus allocated to the "conventional" category, while the roughly 11% of students who took a lower level course in grade 10 (i.e., Algebra I or lower) are in the "low" category and the remaining 37% of students who took a higher level course (that is, Algebra II or above) are in the "high" category. Table A3 in the appendix shows the math course levels associated with the low, conventional, and high trajectory categories for each grade level.

Finally, we examine students' *math course achievement* with two variables: their average course mark (on a scale of 0 to 100%) and whether they failed or withdrew from a math class. These achievement measures are calculated across all courses students took in a given grade level, not just those that they successfully passed.

Disruption to In-Person Instruction

In addition to school-year fixed effects, we measure disruption to in-person instruction as the *share of the 2020-21 school year a student spent in remote learning.* If school years account for broad temporal trends and a host of other decisions schools, districts, and the state may have made in a particular year during the COVID-19 pandemic, the proportion of time students spent in remote instruction focus on this particular decision about the modality of schooling. In response to the COVID-19 pandemic, MA DESE augmented its collection of student attendance data in the SIMS by incorporating the number of days students were present or absent in a remote setting. We calculate our measure as a proportion by dividing the total number of days a student was present in or absent from a remote setting, by the total number of days a student was enrolled in the school year. In our analyses, we model remote instruction in two ways. First, we treat remote instruction as a continuous variable (ranging from 0 to 1). Second, similar to other studies (e.g., Darling-Aduana et al. 2022), we categorize students into three groups based on the percentage of days in remote instruction: (i) less than 50%, (ii) between 50% and 95%, and (iii) greater than 95%. This categorical measure helps to illustrate our findings and allows us to test whether there is a non-linear relationship between remote instruction and math advancement.[4]

Student and School Characteristics

The administrative data also contain rich information about student characteristics. We focus on students' *race/ethnicity* (White; Black; Hispanic; Asian; other) and *economic disadvantage* (a binary variable).[5] We further control for students' *gender* (male; female; non-binary), *English language learner* status (yes/no), eligibility to receive *special education* services (yes/no), and *mobility* (with a binary variable indicating whether a student changed schools either between the 9th and 10th grades or between the 10th and 11th grades). These characteristics are important to account for because they are related to both math course-taking patterns (Han et al. 2023) and remote learning (Singer 2025b). We also adjust our models for prior math attainment and achievement with two variables: (1) a three-category measure of students' *prior math course* (using the low, conventional, and high categories described above, applied to the course students took in either grade 9 or 10 for our analyses of math advancement in grade 10 to 11, respectively) and (2) students' score on their *grade 8 state standardized test in math* (which we standardize within the year a student took the

[4]We performed several robustness checks on our findings. First, we substituted this individual-level measure for district-level data capturing the percentage of the 2020-21 school year spent in either virtual or in virtual or hybrid instruction (COVID-19 School Data Hub 2023). Results are substantively similar, though we prefer the more granular, student-level measure. In addition, we experimented with alternative ways of cutting the continuous remote measure, including into deciles, quintiles, and quartiles. Again, the results are all generally consistent. We stick with this 3-category measure for its parsimony and its more intuitive interpretation, as the categories reflect qualitatively low, moderate, and high shares of the 2020-21 school year spent in remote instruction.

[5]Consistent with research highlighting the limitations of the more traditional measure of low-income status based on free or reduced-price lunch eligibility (Chingos 2016; Domina et al. 2018), the 2019 MA Student Opportunity Act required the Department of Elementary and Secondary Education (DESE) to modify its definition of low-income. During the years in our observation period, low-income (or "economically disadvantaged") students were those who participated in one or more of the following state-administered programs: the Supplemental Nutrition Assistance Program (SNAP), the Transitional Assistance for Families with Dependent Children (TAFDC), the Department of Children and Families' (DCF) foster care program, and certain MassHealth programs.

exam). School-level characteristics include whether it is a *charter school* and located in an *urban* locale, its total *enrollment*, and the *percentage of its students living in poverty*.[6] Table A4 in the appendix shows the descriptive statistics for our sample.

Missing Data

A small number of students (representing 0.02% of students in our sample) were in schools that could not be matched to CCD data to obtain school characteristics and were thus excluded from the analysis. An additional 3.4% of students did not have enough transcript information to observe their prior math course; these students were also excluded. However, larger shares were missing their grade 8 standardized test score in math (11.3%)[7] or their average mark in math courses (5.5%). To address the missingness in MCAS scores and course marks, we use multiple imputation by chained equations to generate five imputed datasets per grade (Kuhfeld et al. 2025). We use our student– (gender, race, economic disadvantage, English language learners, and special education status) and school-level (charter, urbanicity, enrollment, and poverty) variables as covariates in the multiple imputation model.

Analytic Strategy

Consistent with federal guidance on conducting descriptive research in education and given our use of administrative data on a population of students with large sample sizes,

[6]In the Urban Institute's definition, poverty captures family incomes up to 100 percent of the federal poverty level.

[7]All students who are educated with MA public funds participate in the Massachusetts Comprehensive Assessment System (MCAS). Students take a math test in grades 3–8 and 10; we use students' grade 8 test scores to measure their pre-high school aptitude in math. Students in our data, who were in grade 9 between 2016-17 and 2019-20, generally took their grade 8 MCAS tests between 2014-15 and 2018-19. However, students may be missing a score from grade 8 for a number of reasons. Some students in our were not enrolled in MA public schools when they were in grade 8. More substantially, in 2014-15 and 2015-16, districts in MA were given the option of administering the traditional MCAS or participating in the Partnership for Assessment of Readiness for College and Careers (PARCC) program to their students in grades 3–8. About 54% and 72% of districts opted to administer the PARCC exam in 2014-15 and 2015-16, respectively, although the majority of participating schools chose to have their students also take the MCAS. Note, also, that MA rolled out a redesigned ("Next-Generation") MCAS assessment in grades 3–8 beginning in 2016-17. To deal with this change in our analyses, we standardize students' grade 8 math test scores by year.

across our analyses, we do not emphasize statistical significance and instead focus on descriptive patterns (Loeb et al. 2017; Huffaker et al. 2025). Our analyses proceed in four stages. First, we describe students' exposure to remote instruction during the 2020-21 school year and examine how variation in remote instruction is related to student and school characteristics. Second, we present descriptive statistics of students' relative and absolute curricular attainment as well as their achievement in math by grade level, school year, and the proportion of time students spent in remote instruction during 2020-21.

Third, we estimate multilevel models of advancement in math, with students nested in schools. Because our outcome is a binary indicator for whether a student advanced in math between one grade and the next, the level-1 model specifies a logistic regression. School random effects account for the dependency of students within schools.[8] From null models (that is, models of math advancement that include only the school random effects), we find intraclass coefficients—or the proportion of variance in the outcome accounted for by cluster (school) membership—of .47 for both grade 10 and grade 11, suggesting a relatively high degree of school-level clustering in whether students advance in math. This is expected since schools vary in the math courses they are able to offer as well as the resources, organizational rules, and counseling, all of which pattern the availability, opportunities, and constraints for students' coursetaking (McFarland 2006; Tyson and Roksa 2016). Models were estimated separately for each grade level. Base models include either our continuous or categorical measure of remote instruction, school-year fixed effects, and the student– and school-level controls. Finally, to examine whether the relationship between remote instruction and math advancement varies by student subgroup, we add interaction terms between the continuous measure of remote instruction and either economic disadvantage and race/ethnicity to our core models. To aid in the interpretation of these interaction models, we present differences in predicted probabilities of math advancement between groups in each school year and at

[8]We estimated both logistic regression models with school clustered standard errors and our multilevel models with school random effects. Although the results are substantively similar (i.e., coefficients are in the same direction and of generally the same magnitude and statistical significance), likelihood ratio tests suggest the multilevel models provide a significantly better fit to the data.

representative values of the proportion of 2020-21 spent in remote instruction.[9]

Findings

Exposure to remote instruction during the 2020-21 school year

As Figure 1 makes clear, access to in-person versus remote schooling varied widely across high school students in Massachusetts. Most students spent at least some portion of the 2020-21 school year in remote instruction, and they spent a majority of the year in virtual schooling. Indeed, students spent an average of 59.7% of the year in remote instruction (the median is similar at 57.6%). About 39.3% of students spent less than 50% of the school year in remote instruction, 45.2% spent between half and 95% of the year learning remotely, and the remaining 15.4% were educated virtually for more than 95% of the school year.

Figure 1 about here

At the same time, the duration of remote instruction in 2020-21 was non-randomly distributed and varied by both school and student characteristics in ways that reflect previously documented patterns of school closures (Singer 2025a;b; Jack and Oster 2023). As Table 1 shows, students in charter, urban, and larger schools were substantially over-represented among those who received remote instruction for at least half of the 2020-21 school year. This reflects in part the resistance among larger urban districts (e.g., Boston, Worcester, and Springfield) to return to in-person schooling (Hanson 2020). Similarly, the average percent of students in poverty increases as the the share of the year spent in remote instruction increases. Consistent with these patterns by school-level characteristics, economically disadvantaged, Black, and Hispanic students were more likely to receive remote instruction for half or more of the 2020-21 school year. Students who spent longer in virtual schooling were also more likely to have limited English proficiency and had lower 8$^{\text{th}}$ grade standardized math test scores.

[9] Models are estimated separately on each multiply imputed dataset using the *lme4* package in R (Bates et al. 2015) and pooled using Rubin's rules with the *easystats* package (Lüdecke et al. 2022).

Table 1 about here

Changes to Students' Math Coursetaking During the Pandemic

Table 2 provides a descriptive look at trends over time and by remote instruction in 2020-21 in students' relative and absolute curricular attainment and achievement in math. Students in grade 10 slightly decreased the rate at which they advanced in math and markedly increased the rate of repeating their same level as in grade 9 in the first year of the pandemic (2019-20). These trends continue into 2020-21, with substantial variation by the proportion of time students spent in remote instruction. Compared to students who spent less than half of the year in virtual learning settings, 10^{th} graders who spent nearly the full year in remote instruction were much less likely to advance in math and more likely to repeat a level or take or pass no math course. Indeed, just 65% of students who spent nearly all of 2020-21 in remote instruction took a higher level math course in grade 10 than in grade 9. These students in nearly full remote instruction were much more likely to take a low level course (for 10^{th} grade, this includes Algebra I or lower), received lower marks in their math courses, and were more likely to fail or withdraw from a math course.

Table 2 about here

The patterns are similar among students in grade 11. Those who spent more time in remote instruction were less likely to advance and more likely to step down, repeat a level, or take no math than students who spent less of 2020-21 in remote learning or who transitioned to 11^{th} grade prior to the pandemic. Longer time in remote instruction among 11^{th} graders is also related to a higher likelihood of taking a lower-level math class (i.e., Geometry or lower), lower course marks, and a higher failure or withdrawal rate.

Given that the duration of remote instruction in 2020-21 varied by student and school characteristics, we turn next to a more systematic investigation of the relationship between remote instruction during the pandemic and students' likelihood of advancing in math by accounting for student– and school-level factors in our multilevel logistic regression models with school random effects. We present the results of these models in Table 3. Models 1 and 3 include a continuous measure of the proportion of the 2020-21 school year students spent in remote instruction, and models 2 and 4 include a categorical measure of remote instruction.

The results largely confirm our prior descriptive findings. Both 10th and 11th graders were less likely to advance in math in 2020-21 as compared to prior to the pandemic (in 2018-19). Remote instruction is also negatively related math advancement. Among grade 10 students, students who spent at least half of 2020-21 in remote instruction were less likely to advance in math than students who spent less than half of the year in remote instruction. Among 12th graders, those most affected were in the high remote instruction group. Additionally, economically disadvantaged students are substantially less likely than their more advantaged counterparts to advance in math, as are Hispanic and (in grade 11) Black students relative to White students. Asian students are more likely than White students to advance in math between one grade and the next.

Table 3 about here

Other student and school-level factors operate as expected. Women are more likely than men to advance in math in either grade 10 or grade 11, while students with limited English proficiency, eligible for special education services, or who had changed schools are less likely. Students' prior math attainment and achievement are also meaningful predictors of advancement in math. Compared to 10th and 11th graders who took low level courses in grade 9 or 10, respectively, students who took conventional level courses are much more likely to advance in math. This is consistent with the descriptive results from earlier and with prior literature (e.g., Schneider et al. 1997; Lucas 1999; Han et al. 2023), and illustrates the hierarchical nature of high school mathematics and the positional advantages associated with beginning at a higher level. Students who take a prior grade course at the high level (i.e., Geometry or above in grade 9 or Algebra II or above in grade 10) are less likely to advance in grades 10 or 11. This is not all that surprising: These are students who have comparatively fewer rungs of the math sequence left to climb and who likely spend additional time in the "advanced math" category, which is comprised of many different courses (including trigonometry, higher levels of Algebra, and probability and statistics). Standardized math test scores in middle school are positively associated with math advancement. Students in urban high schools are also less likely to advance in math.

Heterogeneity by Economic Disadvantage and Race/Ethnicity

Finally, we examine whether the relationship between students' math advancement and the pandemic as well as remote instruction vary by economic disadvantage or race/ethnicity. To models 1 and 3 in Table 3, we add an interaction between the continuous measure of remote instruction and either economic disadvantage or race/ethnicity (abbreviated model results can be found in Tables A5 and A6 of the appendix). We then predict probabilities of math advancement using our model results for each student. Because we multiply imputed our data to address missingness in students' grade 8 standardized math test scores, we estimate the predicted probabilities separately in each imputed dataset and then combine them using Rubin's rules (Miles 2016). In Figures 2 and 3, we plot the differences in the predicted probability of math advancement by year and the representative values of the share of the 2020-21 school year students spent in remote instruction.

FIGURE 2 ABOUT HERE

Figure 2 presents the results for economically disadvantaged and non-disadvantaged students. Accounting for a rich set of individual and school-level characteristics, economically disadvantaged students are substantially less likely than their more advantaged peers to advance in math in any given school year. Prior to the pandemic, the difference between economically disadvantaged and non-disadvantaged students was approximately 5–6 percentage points in both grades 10 and 11. In 2020-21, the overall gap grew to more than

8 percentage points. However, this increase in the size of the gap is driven by variation in exposure to remote instruction. Among students who spent no part or very little of the 2020-21 school year in remote learning, the gap by economic disadvantage is no larger than it is in years prior to the pandemic. But the gap in math advancement among those who spent all or nearly all of the 2020-21 school year in remote instruction is roughly twice as large. Among 10th and 11th graders who spent the full year learning in virtual settings, economically disadvantaged students were about 11 percentage points less likely than non-disadvantaged students to advance in math.

FIGURE 3 ABOUT HERE

The patterns are broadly similar by race/ethnicity, shown in Figure 3, though the race-based gaps in math advancement are not as large as the economic disadvantage disparities. We focus on the differences between Black and Hispanic students on the one hand and White students on the other to conserve space.[10] Across all four school years, in both grades 10 and 11, there is virtually no difference in the likelihood of advancing in math between Black and White students. A small gap emerges only among students who spent more time during the 2020-21 school year in remote instruction. At 100% of the school year in virtual learning, the Black-White gap increases to increasing to 2.7 and 4.2 percentage points in grades 10 and 11, respectively. The baseline gaps between Hispanic and White students are larger—about 2–3 percentage points in each year and grade—but again they grow only as the share of the 2020-21 school year spent in remote instruction increases. At very low levels of remote learning, the Hispanic-White gaps are similar in size as the pre-COVID differences. At 50% remote, the Hispanic-White gap in the predicted probability of math advancement increases to 4.8 percentage points in grade 10 and 5.6 percentage points in grade 11. For students who

[10] Asian students advance in math at similar rates as White students prior to the pandemic; they hold just a small 1 and 2 percentage point advantage in grades 10 and 11, respectively, between 2017-18 and 2019-20. Their advantage is larger in 2020-21 at higher levels of remote instruction; at 100% remote instruction, Asian students are about 4.4 percentage points more likely than their White counterparts to advance in math. Students of other racial groups occupy a middle ground between Black and Hispanic students in terms of their gaps to White students.

spent the full year in remote instruction, the gaps between Hispanic and White students are roughly 8 percentage points.

Conclusion

In this study, we set out to describe how high school students' attainment and achievement in math changed during the COVID-19 pandemic and in relation to the move to remote instruction. We highlight three core findings. First, learning modality during the pandemic was non-randomly distributed, and students' exposure to virtual schooling varied systematically with both school and individual-level characteristics. Though remote instruction was widespread—roughly 60% of high school students spent more than half of the year in remote learning—students in large, urban high schools spent substantially more time in virtual settings than students who attended smaller schools or schools in suburban or rural locales. Relatedly, economically disadvantaged, Black, and Hispanic students were much more likely to spend longer periods of the 2020-21 school year in remote instruction as well.

Second, students who transitioned to grades 10 or 11 during the pandemic had lower levels of math attainment and achievement. More specifically, they were much less likely to advance in math, more likely to fail or withdraw from a math course, take lower-level courses, and receive lower course grades. Students who spent more time in remote instruction during 2020-21 had particularly lower levels of math advancement, and this negative relationship persists even when accounting for a host of student– and school-level characteristics. This finding is related to the path dependent and consequential nature of high school math course-taking. The level of math at which students begin high school shapes the opportunities available to them to attain more advanced courses by the time they leave high school (Schneider et al. 1997; Lucas 1999). At the same time, regardless of where students begin, falling off track—by stepping down, repeating a level, or otherwise failing to advance—constrains how far up the math ladder they will be able to climb and thus limits the valuable skills and credentials students will attain by the end of high school for postsecondary education and the labor market. The pandemic in general and the shift to remote learning in particular therefore disrupted students' opportunities to complete higher levels of math in high school.

Third, this disruption was unevenly experienced across student subgroups. We find evidence of widening gaps in math advancement at longer durations of remote instruction by student demographics, particularly by socioeconomic status. The average difference in math advancement by economic disadvantage grew during the pandemic and the size of the gap varied by the time spent in remote learning during the 2020-21 school year. Indeed, the difference between economically disadvantaged and non-disadvantaged students is nearly twice as large among students who spent all or nearly all of the year in remote instruction as compared to the gap at very low levels of remote instruction. The pattern is similar among Black and especially Hispanic students relative to their White peers, though the gaps and the trend by remote status are not as stark as for economic disadvantage.

Our findings contribute to the broader scholarship on the negative impacts of the pandemic to learning. Whereas others have found that math and reading test scores, attendance, high school completion, and postsecondary enrollment all declined during the pandemic (e.g., Engzell et al. 2021; Goldhaber et al. 2023; Liu 2023; Denice and Andersen 2025; Singer 2025a), we add advancement in the high school math course sequence to this lengthy list. Given the strong relationships between high school math attainment and educational and occupational outcomes (Riegle-Crumb 2006), math advancement can be thought of as a leading indicator of future, longer-term repercussions. And given the widening gaps in math advancement found by student socioeconomic status and race/ethnicity, these downstream consequences will be unevenly experienced.

Relatedly, because we find that disparities in math advancement were larger at longer durations of remote learning for economically disadvantaged, Black, and Hispanic students, our study's findings are situated in the debates over the utility of closing schools as a policy response to the pandemic. Public health officials and education leaders can hardly be faulted for responding to a once-in-a-generation health, economic, and social crisis in the heat of the moment with so little information at hand. At the same time, the emerging consensus is that school closures and the move to remote instruction did little to reduce the spread of COVID-19 (Esposito and Principi 2020; Marsden 2025). Part of this may be due to the fact that school closures and the decisions to return to in-person schooling were not tied only to rates on infection (Harris and Oliver 2021). Instead, as Table 1 suggests and other research corroborates (Singer 2025a;b; Jack and Oster 2023), school closures were concentrated in districts and schools with higher shares of students of color and students from lower socioeconomic backgrounds. And racial disparities in school re-openings persist even after accounting for the prevalence of COVID-19 (Landivar et al. 2022). Alongside debates about the utility of transitioning to remote instruction, this and other research makes clear the toll taken by prolonged school closures on students' learning as well as on their physical, mental, and social well-being (Tan 2021).

Our study is not without its limitations. Data come from a single U.S. state, and states vary in terms of their student demographics as well as their curricular frameworks. A higher share of students in MA as compared to the U.S. are White (56.8% versus 45.7% or Asian (7.2% versus 5.4%), and a lower share are Black (9.3% v. 15.0%) or Hispanic (22.3% v. 28.1%) (NCES 2022: Table 203.70). MA students are also less likely to attend schools in urban locales (17.4%) than in the U.S. overall (29.8%) (NCES 2022: Table 203.72). Further, MA boasts some of the best achievement outcomes in the U.S., including higher-than-average shares of 18-24-year-old adults enrolled in degree-granting postsecondary institutions (51.8% in MA compared to 40.9% in the U.S. in 2021) (NCES 2022: Table 302.65) and scores on international standardized tests that rival the highest-scoring countries (Carnoy et al. 2015). In 1993, MA passed a major reform law to pursue rigorous academic goals and increase its investment in K-12 education to help schools, teachers, and students achieve those goals (Tanden and Reville 2013). One stipulation of this law was to develop high school exit exams in core academic subjects, including math (Papay et al. 2010). Nationally, such exit exams have been linked to an increased likelihood of completing precalculus or higher in high school

(Han et al. 2024). In some ways, then, MA could be considered a best case scenario in terms of observing the pandemic's association with students' advancement in high school math courses. Thus, while we take advantage of detailed, individual-level, longitudinal data on students' coursetaking in math, our study leaves open the opportunity for other research to confirm the patterns we uncover elsewhere. That said, according to district-level schooling mode data, MA had roughly average rates of virtual instruction during the 2020-21 school year (Jack et al. 2023). Additionally, the math coursetaking trajectories we identify are broadly consistent with those found in nationally representative samples (e.g., Han et al. 2023).

Our analyses also exclude those students who attended schools outside of the public secondary school system. This comprises a small share of students in MA; only about 8% of the state's students were educated in private, non-public schools during the 2019-20 school year,[11] which is roughly on par with the national average (NCES 2022: Tables 203.10, 205.20). However, we are unable to speak to whether or how rates of math advancement may have changed during the pandemic among the non-trivial and—during COVID—growing population of students who were educated outside of the public system (Bacher-Hicks et al. 2023), in private schools or at home. To the extent that non-public students tend to be more advantaged (Carbonaro 2006), we may underestimate socioeconomic and racial/ethnic gaps.

In addition, while we find an association between the pandemic generally and remote instruction more specifically and students' likelihood of advancing in the math course sequence, exposure to remote instruction was not random, either among the students in our data (see Table 1) or elsewhere (Singer 2025a;b; Jack and Oster 2023). As a result, we do not identify a causal effect, and we are careful to note that our findings could reflect a range of other factors that are associated with remote instruction, including conditions in students' homes and communities that may elevate families' concerns about their health and safety

[11] Authors' calculations of publicly available enrollment data from the MA DESE (available here: https://profiles.doe.mass.edu/statereport/enrollmentbygrade.aspx, and here: https://profiles.doe.mass.edu/statereport/nonpublicschoolreport.aspx).

(e.g., housing instability or overcrowding, and variation in exposure to the COVID-19 virus) or the resources schools and districts had at their disposal to manage in-person schooling safely.

In sum, our findings highlight the negative relationship between the COVID-19 pandemic and an important educational outcome: students' progress through the high school math sequence. The consequences of the pandemic will be broader and longer-term than just learning in the short-run. School closures have already been shown to reduce the lifetime income and inter-generational mobility of the students affected (Jang and Yum 2024). One study predicts that U.S. students affected by school closures during the pandemic will experience a long-term earnings drop of 1.8% (Fuchs-Schündeln 2022). Given the relationship between high school math attainment and longer-term educational and occupational outcomes, the patterns described here will have wide- and far-reaching implications for both individuals' life course outcomes and patterns of inequality among population groups.

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Tables

Table 1: Student and school characteristics by share of the 2020-21 school year spent in remote instruction

	<50% remote	50-95% remote	>95% remote
Student characteristics			
Economically disadvantaged	0.206	0.341	0.513
White	0.767	0.577	0.293
Black	0.043	0.093	0.180
Hispanic	0.099	0.226	0.362
Asian	0.054	0.065	0.129
Other	0.037	0.039	0.037
Male	0.525	0.499	0.460
Female	0.474	0.500	0.539
Non-binary	0.000	0.000	0.000
Limited English proficiency	0.029	0.068	0.114
Special education	0.186	0.152	0.152
Student mobility	0.027	0.024	0.029
MCAS 8th grade math	0.155	0.012	-0.202
School characteristics			
Charter school	0.009	0.059	0.106
School is in urban locale	0.022	0.176	0.496
School enrollment	1112.268	1357.625	1456.315
School percent in poverty	4.162	7.857	12.420
N	51,565	59,314	20,213
%	39.3	45.2	15.4

Notes: Table shows descriptive statistics of student and school characteristics for students in grades 10 and 11 in 2020-21 by our categorical measure of the share of days spent in remote instruction.

Table 2: Math attainment and achievement, by grade, school year, and remote instruction

	2017-18	2018-19	2019-20	2020-21, by remote instruction: <50%	50-95%	>95%
Grade 10						
Relative curricular attainment						
Advance	81.08	79.34	77.72	75.53	75.49	65.19
Down	6.98	8.31	7.67	10.04	5.43	9.11
Repeat	7.24	7.91	11.00	9.96	10.20	13.26
No math	4.70	4.44	3.61	4.48	8.88	12.45
Absolute curricular attainment						
Low	10.25	10.41	9.85	11.91	13.82	18.10
Conventional	53.04	51.31	51.88	53.03	49.68	47.76
High	36.71	38.28	38.27	35.05	36.51	34.14
Math achievement						
Average mark	81.00	81.22	83.64	83.84	80.69	78.48
Fail/withdraw	12.24	12.22	11.89	13.74	19.45	22.50
N	63,687	63,285	65,422	25,429	30,461	9,859
Grade 11						
Relative curricular attainment						
Advance	81.45	83.13	85.05	85.71	79.34	67.21
Down	4.75	4.88	4.59	4.17	3.43	7.85
Repeat	6.97	5.63	6.39	4.49	7.84	11.33
No math	6.83	6.36	3.97	5.64	9.39	13.61
Absolute curricular attainment						
Low	15.59	14.39	11.32	12.54	15.68	25.60
Conventional	55.08	53.78	55.76	53.60	53.87	48.08
High	29.34	31.83	32.92	33.86	30.44	26.32
Math achievement						
Average mark	80.24	80.43	83.75	83.55	80.98	78.18
Fail/withdraw	13.76	14.01	11.34	14.19	18.67	22.00
N	64,379	63,696	63,226	26,136	28,853	10,354

Notes: Table displays percentages showing the distribution of curricular moves and achievement in mathematics, by grade level, academic year, and the share of days spent in remote instruction during the 2020-21 school year.

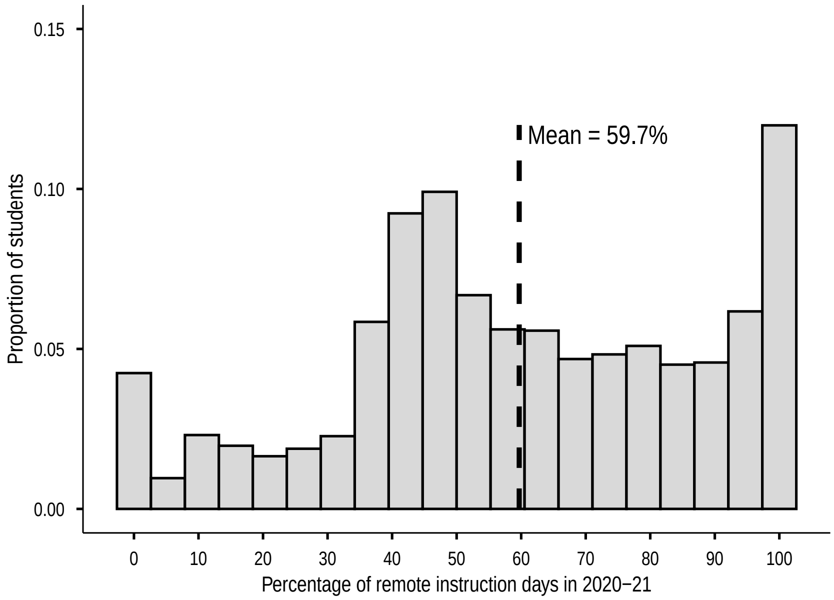
Table 3: Mixed-effects logistic regression results predicting advancement in math, by grade level

	Grade 10		Grade 11	
	Model 1	Model 2	Model 3	Model 4
2017-18 (ref.=2018-19)	1.127***	1.127***	0.881***	0.883***
	(0.025)	(0.025)	(0.018)	(0.018)
2019-20	0.954*	0.954*	1.252***	1.252***
	(0.018)	(0.018)	(0.024)	(0.023)
2020-21	0.718***	0.703***	0.890***	0.823***
	(0.026)	(0.018)	(0.031)	(0.021)
Remote (proportion)	0.854**		0.845***	
	(0.043)		(0.040)	
Remote: 50-95% (ref.=<50%)		0.886***		1.026
		(0.027)		(0.031)
Remote: >95%		0.886**		0.823***
		(0.036)		(0.031)
Economically disadvantaged	0.647***	0.647***	0.660***	0.660***
	(0.011)	(0.011)	(0.010)	(0.010)
Black (ref.=White)	0.956	0.956	0.950*	0.950*
	(0.027)	(0.027)	(0.024)	(0.024)
Hispanic	0.805***	0.805***	0.786***	0.787***
	(0.018)	(0.018)	(0.016)	(0.016)
Asian	1.127***	1.127***	1.181***	1.186***
	(0.032)	(0.032)	(0.034)	(0.034)
Other	0.918*	0.918*	0.868***	0.868***
	(0.034)	(0.034)	(0.030)	(0.030)
Female (ref.=Male)	1.182***	1.182***	1.233***	1.233***
	(0.016)	(0.016)	(0.016)	(0.016)
Non-binary	0.881	0.880	0.617*	0.617*
	(0.196)	(0.196)	(0.122)	(0.122)
Limited English proficiency	0.661***	0.661***	0.715***	0.715***
	(0.019)	(0.019)	(0.019)	(0.019)
Special education	0.518***	0.517***	0.422***	0.422***
	(0.010)	(0.010)	(0.007)	(0.007)
Student mobility	0.502***	0.502***	0.416***	0.416***
	(0.015)	(0.015)	(0.013)	(0.013)
Prior math: Conventional (ref.=Low)	3.707***	3.709***	1.448***	1.446***
	(0.089)	(0.089)	(0.030)	(0.030)
Prior math: High	0.180***	0.180***	0.449***	0.448***
	(0.005)	(0.005)	(0.011)	(0.011)
MCAS 8th grade math	2.112***	2.112***	1.945***	1.945***
	(0.022)	(0.022)	(0.017)	(0.017)
Charter school	0.917	0.920	1.242	1.242
	(0.228)	(0.229)	(0.278)	(0.278)
School is in urban locale	0.680	0.679	0.463***	0.473***
	(0.145)	(0.145)	(0.088)	(0.090)
School enrollment	1.021	1.028	1.062	1.056
	(0.060)	(0.060)	(0.061)	(0.061)
School percent poverty	0.914	0.914	0.896*	0.885**
	(0.046)	(0.046)	(0.041)	(0.041)
Constant	11.243***	11.297***	11.325***	11.295***
	(1.152)	(1.157)	(1.043)	(1.039)
N students	258143	258143	256644	256644
N schools	403	403	407	407
sd(schools)	1.555	1.555	1.389	1.388

Notes: Table displays odds-ratios (standard errors in parentheses). *p < .05; **p < .01; ***p < .001

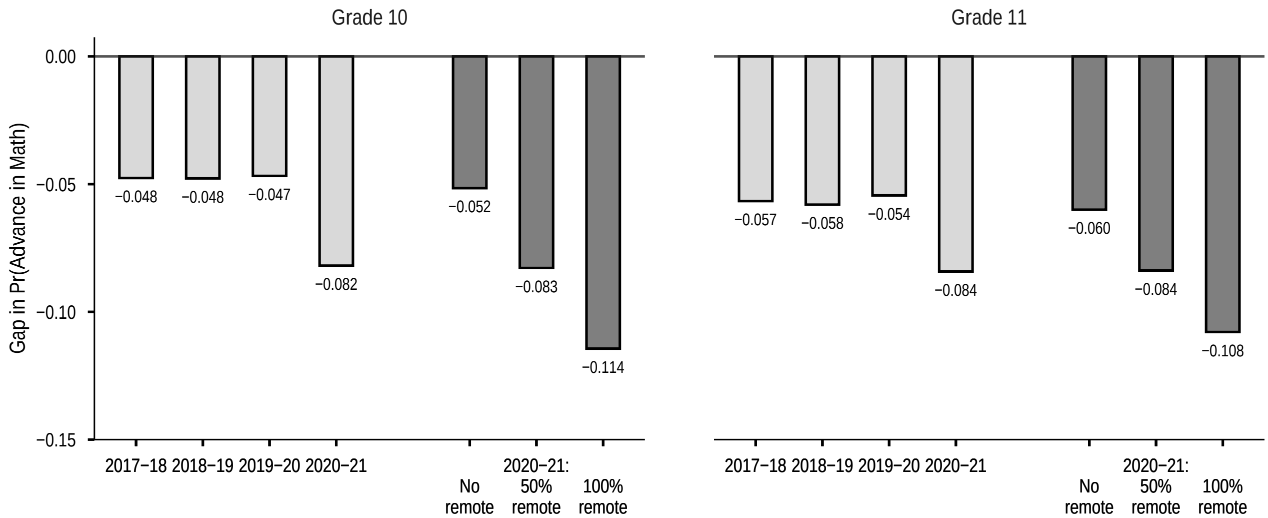
Figures

Figure 1: Share of time spent in remote instruction during the 2020-21 school year



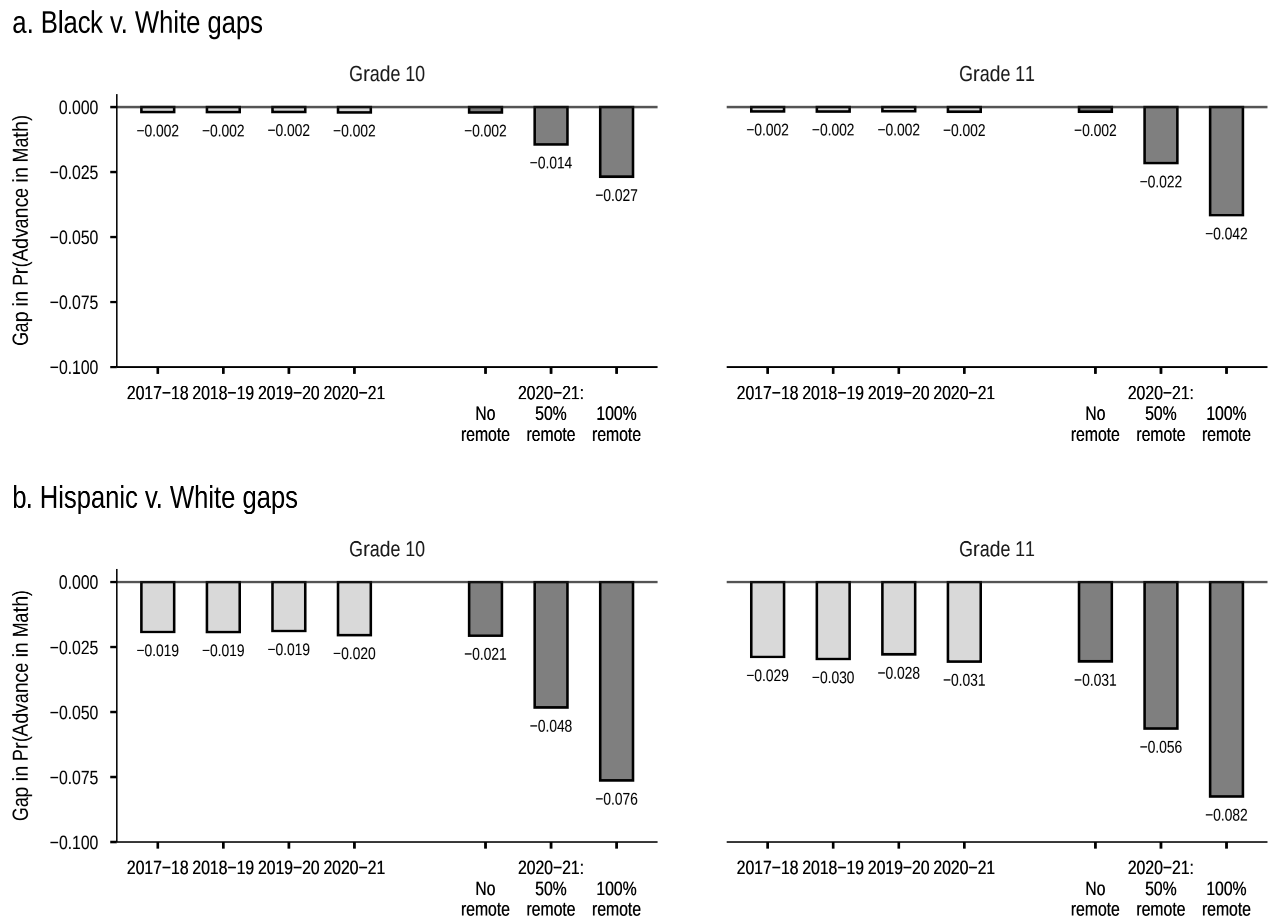
Notes: Figure depicts a histogram of the share (percentage) of days during the 2020-21 school year students in grades 10 and 11 were instructed in a remote setting.

Figure 2: Differences between economically disadvantaged and non-disadvantaged students in the predicted probability of math advancement by grade and remote instruction



Notes: The x-axis shows the school year or, in 2020-21, the percentage of the year spent in remote instruction (0%, 50%, 100%). The y-axis is the gap in the predicted probability of math advancement between economically disadvantaged and non-disadvantaged students. Model parameters can be found in Table A5 of the appendix.

Figure 3: Predicted probabilities of math advancement by grade, remote schooling, and race/ethnicity



Notes: The x-axis shows the school year or, in 2020-21, the percentage of the year spent in remote instruction (0%, 50%, 100%). The y-axis is the gap in the predicted probability of math advancement between Black or Hispanic students and White students. To conserve space, we exclude Asian and "other" students from this figure. Model parameters can be found in Table A6 of the appendix.

Appendix A: Supplemental Tables

Table A1: Sample restrictions

	N students	N student-year records
Initial N: All public and charter school students in grades 9–12 in years 2016-17 to 2021-22 in SIMS data	781,030	2,100,389
Keep those whose enrollment status includes enrolled, graduated, dropped out, received certificate of attainment, completed 12th grade, or transferred in-state	757,494	2,044,345
Keep those who we observe for at least two consecutive years and grades, and who did not skip or repeat a high school grade level	535,920	1,704,235
Drop those in districts with missing SCS data[a]	532,221	1,692,022
Keep those in grades 10 and 11 in 2017-18 to 2020-21	333,778	526,073
Drop those with missing school-level information	327,567	514,787

Notes: Table shows the numbers of students and student-year records that remain after restricting our sample. The final analytic sample appears in the bottom row. There are similar numbers of students in each grade and year (about 64,000).
[a]According to DESE's Researcher's Guide to MA Educational Data, two districts (Medford and South Hadley) are missing SCS data in 2015-16; students in either cohort in these districts are excluded from the sample since they would be missing a year of their course-taking information.

Table A2: Hierarchy of math courses

	Category	Examples
0	No math	No passed math course
1	Basic or other math	General, foundation, consumer, & business math; pre-algebra
2	Algebra I	Algebra I
3	Geometry	Geometry; analytic or informal geometry
4	Algebra II	Algebra II
5	Advanced math	Trigonometry; Algebra III; Probability & statistics
6	Pre-calculus	Pre-calculus, AP pre-calculus
7	Calculus	Calculus; AP calculus AB or BC

Table A3: Absolute curricular attainment categories, by grade level

	Low	Conventional	High
Grade 9	Pre-algebra	Algebra I	Geometry or above
Grade 10	Algebra I or lower	Geometry	Algebra II or above
Grade 11	Geometry or lower	Algebra II or advanced math	Pre-calculus or above
Grade 12	Algebra II or lower	Advanced math or pre-calculus	Calculus

Table A4: Descriptive statistics

	Overall	2017-18	2018-19	2019-20	2020-21
Student characteristics					
Economically disadvantaged	0.263	0.233	0.236	0.266	0.314
White	0.637	0.659	0.651	0.633	0.608
Black	0.083	0.081	0.082	0.083	0.087
Hispanic	0.175	0.161	0.165	0.177	0.197
Asian	0.070	0.068	0.070	0.072	0.071
Other	0.034	0.031	0.032	0.035	0.038
Male	0.499	0.498	0.496	0.499	0.503
Female	0.500	0.502	0.503	0.500	0.496
Non-binary	0.000	0.000	0.000	0.000	0.000
Limited English proficiency	0.049	0.046	0.044	0.047	0.060
Special education	0.157	0.158	0.151	0.155	0.165
Student mobility	0.033	0.035	0.035	0.035	0.026
MCAS 8th grade math	0.046	0.034	0.052	0.061	0.036
School characteristics					
Charter school	0.043	0.040	0.042	0.044	0.047
School is in urban locale	0.158	0.155	0.154	0.157	0.165
School enrollment	1270.974	1269.408	1267.385	1270.617	1276.331
School percent poverty	7.388	8.346	7.009	7.095	7.107
N	514,787	128,066	126,981	128,648	131,092

Notes: Table shows descriptive statistics of student and school characteristics for the sample overall and by academic year.

Table A5: Mixed-effects logistic regression results predicting advancement in math, with interaction between remote instruction and economic disadvantage, by grade level

	Grade 10	Grade 11
2017-18 (ref.=2018-19)	1.140***	0.887***
	(0.025)	(0.018)
2019-20	0.951**	1.250***
	(0.018)	(0.023)
2020-21	0.677***	0.860***
	(0.025)	(0.030)
Remote (proportion)	1.113	1.005
	(0.065)	(0.054)
Economically disadvantaged	0.702***	0.696***
	(0.013)	(0.012)
Remote x economically disadvantaged	0.656***	0.755***
	(0.029)	(0.031)
Constant	11.058***	11.272***
	(1.132)	(1.034)
N students	258143	256644
N schools	403	407
sd(schools)	1.553	1.382

Notes: Table displays odds ratios (standard errors in parentheses). Models contain the same covariates as in Table 3.
*p < .05; **p < .01; ***p < .001

Table A6: Mixed-effects logistic regression results predicting advancement in math, with interaction between remote instruction and race/ethnicity, by grade level

	Grade 10	Grade 11
2017-18 (ref.=2018-19)	1.139***	0.889***
	(0.025)	(0.018)
2019-20	0.952*	1.251***
	(0.018)	(0.023)
2020-21	0.688***	0.857***
	(0.026)	(0.030)
Remote (proportion)	1.020	1.003
	(0.064)	(0.058)
Black (ref.=White)	0.982	0.988
	(0.031)	(0.027)
Hispanic	0.867***	0.833***
	(0.021)	(0.018)
Asian	1.070*	1.143***
	(0.034)	(0.036)
Other	0.958	0.885**
	(0.041)	(0.035)
Remote x Black	0.847*	0.794***
	(0.058)	(0.049)
Remote x Hispanic	0.693***	0.739***
	(0.036)	(0.036)
Remote x Asian	1.290**	1.149
	(0.104)	(0.092)
Remote x Other	0.775*	0.877
	(0.089)	(0.093)
Constant	11.129***	11.274***
	(1.140)	(1.033)
N students	258143	256644
N schools	403	407
sd(schools)	1.554	1.381

Notes: Table displays odds ratios (standard errors in parentheses). Models contain the same covariates as in Table 3.
*p < .05; **p < .01; ***p < .001

Appendix B: Describing Students' Math Coursetaking Trajectories

To provide orienting context, this appendix describes students' general high school coursetaking trajectories in math. We pool transcript data across years for those students in our sample whom we observe in all four grade levels, from grade 9 through grade 12. We identify a student's highest level of math course in each grade level and construct a four-course sequence for each student. All told, we observe over 1,700 unique sequences, although most of these are followed by very small numbers of students.

Figure B1 illustrates the relative share of students taking each math level by grade as well as the flows between courses across grades. A few patterns stand out. There is quite a bit of variation in students' starting places in grade 9, which then has implications for how far up the math hierarchy students can go by the time they leave high school. Over half of students in the data take Algebra I in grade 9, but nontrivial shares of students start out with a lower (6%) or higher (40%) course.

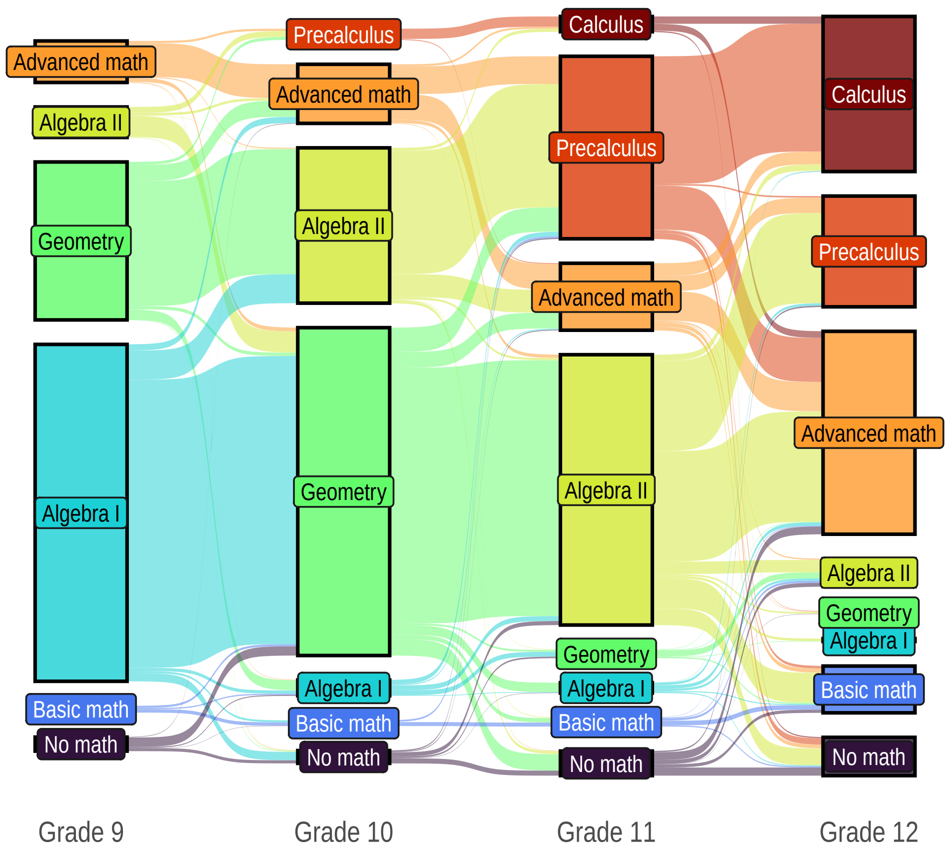
Additionally, coursetaking trajectories vary in their prevalence, direction, and rate of progression (McFarland 2006). Some trajectories (e.g., Algebra I to Geometry to Algebra II to precalculus or another advanced math course) are very common, as evidenced by the thicker flows between nodes, while others are more rare. Similarly, some trajectories move students ever upward along the math hierarchy. For other students, their coursetaking hits a kind of dead end and they either remain at the same level for multiple years or take a later course at a level below a prior one. In a similar way, some students appear to jump more than a single rung in the math hierarchy between two grades, perhaps because they take two courses at the same level in the same year. This allows them to accelerate how quickly they progress up the hierarchy and how far they can attain in high school. For students who remain at a given level across more than one grade, their progress is slowed. Even if they had started out in a similar level in grade 9 as their more accelerated peers, their slower progress means they cannot get as far up the math hierarchy by the end of high school.

Table B1 shows the ten most common coursetaking sequences, which account for over half of the students in our data. The modal pathway, followed by nearly 15% of students, begins with Algebra I in 9th grade, is followed by Geometry and Algebra II, and ends in 12th grade with an advanced math course (e.g., trigonometry or statistics). The second most common pathway (representing about 13% of students) similarly begins with the Algebra I–Geometry–Algebra II sequence, but ends with students completing precalculus in grade 12. Students who are able to reach calculus by the end of high school typically need to start at a level higher than Algebra I. However, students who begin at a lower level can manage to complete calculus by the 12th grade. These students likely pursue an accelerated pathway by "doubling up" math courses in a single year, perhaps by either taking both Geometry and Algebra II in 10th grade (DESE 2017).[1]

In Table B2, we show students' relative (the average number of advancing, down, repeat and no math moves) and absolute (their highest math course) curricular attainment by the level of their first high school math course. Students who begin in either Algebra I or Geometry evince consistent advancement throughout their high school career. Out of a total

[1]Again, we characterize students' math trajectories by taking the highest level math course they pass in each year. In this way, a student who looks like they jumped a level—from Algebra I in grade 9 to Algebra II in grade 10—likely took Geometry in grade 10 as well.

Figure B1: High school students' math coursetaking trajectories



Notes: Figure depicts a Sankey plot showing (nodes) and flows across grades 9 through 12. Sample (N=244,065) includes only those students in our data for whom we observe all four years of high school (grades 9 through 12), and the figure omits a small number of students who follow very rare coursetaking trajectories (i.e., sequences followed by less than 100 students) for the sake of clarity.

of three possible moves (one for each grade transition), these students advance for most of them and are very unlikely to drop down, repeat a level, or not take or fail to pass a math course in a given grade. They also make it quite far up the math ladder by the end of high school. Most students who begin in Algebra I attain at least advanced math by grade 12, and well over half of the students who begin in Geometry are able to complete calculus.

By contrast, the students who start with a course below Algebra I make fewer advancing moves and are more likely to repeat a level or not take or pass a math course. They also end their math sequences in a much lower position, with 60% achieving at most Algebra II by the 12^{th} grade. For the 13.4% of students who begin high school in Algebra II or above, they make fewer advancing moves and more repeat moves than other students. However, this is driven in large part by the number and variety of courses in the "advanced math" category. And about half of these students take calculus by the time they leave high school.

Table B1: The 10 most common math coursetaking trajectories from grade 9 to grade 12

Trajectory	Percentage	Cumulative percentage
Algebra I - Geometry - Algebra II - Advanced math	14.89	14.89
Algebra I - Geometry - Algebra II - Precalculus	12.84	27.73
Geometry - Algebra II - Precalculus - Calculus	10.75	38.48
Algebra I - Geometry - Algebra II - Basic math	3.99	42.47
Geometry - Algebra II - Precalculus - Advanced math	3.98	46.45
Algebra I - Geometry - Algebra II - No math	2.30	48.75
Algebra I - Algebra II - Precalculus - Calculus	1.98	50.73
Algebra II - Geometry - Precalculus - Calculus	1.88	52.61
Algebra I - Geometry - Algebra II - Algebra II	1.74	54.35
Advanced math - Advanced math - Precalculus - Calculus	1.54	55.89

Notes: Table shows the 10 most common math coursetaking trajectories (out of 1,740) among high school students, the percentage of high school students who follow each trajectory, and the cumulative percentage of students. Sample includes only those students in our data for whom we observe all four years of high school (grades 9 through 12); N=244,898.

Table B2: Math attainment, by level of first high school math course

	Overall	Pre-algebra	Algebra I	Geometry	Algebra II or above
Relative curricular attainment: Number of moves					
Advance	2.29	1.69	2.52	2.42	1.37
Down	0.29	0.22	0.19	0.32	0.66
Repeat	0.25	0.49	0.11	0.17	0.85
No math	0.17	0.60	0.17	0.09	0.13
Absolute curricular attainment: Highest math course					
Algebra II or below	18.65	60.18	25.47	3.28	2.09
Advanced math	27.72	26.57	35.90	11.64	26.32
Precalculus	27.07	9.66	30.21	27.76	20.79
Calculus	26.56	3.59	8.43	57.31	50.81
Percent	100.00	6.03	54.51	26.11	13.35

Notes: Table displays percentages showing the distribution of relative curricular attainment (the number of moves up or down, levels repeated, or no math taken and passed) and absolute curricular attainment (the highest level of math course taken over the course grades 9 through 12) by students' first high school math course. Sample includes only those students in our data for whom we observe all four years of high school (grades 9 through 12); N=244,989.