ANNENBERG
BROWN UNIVERSITY

EdWorkingPaper No. 23-734

Ahead of the Game? Course-Taking Patterns under a Math Pathways Reform

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A controversial, equity-focused mathematics reform in the San Francisco Unified School District (SFUSD) featured delaying Algebra I until ninth grade for all students. This descriptive study examines student-level longitudinal data on mathematics course-taking across successive cohorts of SFUSD students who spanned the reform's implementation. We observe large changes in ninth and tenth grades (e.g., delaying Algebra I and Geometry). Participation in Advanced Placement (AP) math initially fell 15% (6 pp.) driven by declines in AP Calculus and among Asian/Pacific-Islander students. However, growing participation in acceleration options attenuated these reductions. Large ethnoracial gaps in advanced math course-taking remained.

VERSION: March 2023

Suggested citation: Huffaker, Elizabeth, Sarah Novicoff, and Thomas S. Dee. (2023).. Ahead of the Game? Course-Taking Patterns under a Math Pathways Reform. (EdWorkingPaper: 23-734). Retrieved from Annenberg Institute at Brown University: https://doi.org/10.26300/yk56-yy47

Introduction

The scope and sequencing of secondary mathematics curricula have become a focal point in broader debates over how schools should simultaneously promote equitable learning opportunities and student excellence. The stakes of this disagreement are high. Access to advanced math courses in high school (i.e. those with content beyond Algebra II) has strong links to longer-run economic success through opening up post-secondary STEM pathways for students (Altonji, 1995; Goodman, 2019; Long et al., 2012). However, ethnoracial gaps in math attainment are large and persistent (Conger et al., 2009). Nationally, 48% of Asian or Pacific Islander students and 22% of White students enroll in Calculus by their senior year, compared with only 14% of Hispanic students and 11% of Black students (Loveless, 2021). The San Francisco Unified School District (SFUSD) has observed comparably stark gaps in course access and failures rates (Carranza, 2015). For example, among SFUSD students who started high school in 2012, only five percent of Black students and seven percent of Hispanic students enrolled in AP Calculus (rates that were three and five times higher among their White and Asian /Pacific Islander peers, respectively). Approximately 40% of each cohort, including a disproportionate share of Black and Hispanic students, was required to repeat Algebra I.

Centering these equity concerns, SFUSD implemented a reform to its math pathways in SY 2014-15 (Carranza, 2015). In a turn away from their previous eighth-grade "Algebra for All" policy, starting with the Class of 2019, the District ceased offering Algebra I prior to ninth grade (Tintocalis, 2015). This practice represented a break from a decades-long national trend towards broadening early access to Algebra I but aligned with features of the newly adopted California Common Core State Standards (CCSS), which had introduced a more rigorous three-year middle school math sequence than had existed under the prior standards (California Department of Education [CDE], 2015). While many districts in California continued to offer Algebra I in eighth grade, this required compressing content across grades 6 and 7. SFUSD did not embrace this strategy. Instead, SFUSD's superintendent positioned the District as trailblazers "ahead of the game" in responding to what some math researchers referred to as the "failed practices of tracking and early acceleration" and a tendency to "rush students through the curriculum so that they can take calculus in their senior year" (Boaler et al., 2018; Carranza, 2015). The architects of the new policy argued that *all* students would be best served by enrolling throughout middle school in the unabridged CCSS sequence (Carranza, 2015).

The controversy over SFUSD's reform has figured prominently in ongoing state and national debates about math pedagogy (Boaler et al., 2018; Boaler & Schoenfeld, 2018; Loveless, 2022; Mo, 2021; Sawchuk, 2018; Tucker, 2019). In particular, the originally proposed new California Math Framework (CMF), which provides non-binding guidance for districts on math policy and practice, recommended delaying Algebra I until ninth grade and emphasizing the Common Core math standards (Boaler et al., 2018; Boaler & Schoenfeld, 2018). Proponents of the CMF have specifically pointed to SFUSD as a model district for its detracking initiative. However, CMF critics argue that expanded detracking and delaying Algebra I holds back high-achieving students and unintentionally introduces new barriers to college readiness, particularly for those interested in STEM fields (Evers & Wurman, 2022; Fensterwald, 2022; Ford, 2022; Hong, 2021). This debate has understandably focused national attention on understanding SFUSD's leading, district-wide reform (Fortin, 2021). However, there is little consensus on what actually transpired among SFUSD students as the reform was implemented amid allegations that publicly reported results are being misrepresented (Mo, 2021).

In this study, we provide evidence on this question through an independent analysis of longitudinal, student-level data from multiple cohorts of SFUSD students who spanned the introduction of the math pathways reforms. More specifically, we focus on three broad research questions. How did high school math course-taking patterns change in the years after the implementation of the pathways policy? How did student performance in high school math courses (i.e., credits earned) change after the reform's implementation? And, finally, we ask how these changes varied across ethnoracial subgroups, whose pre-reform differences provided a central motivation for this policy initiative. Our study does not aim to provide policy recommendations or to assess the effects of this reform on every relevant student outcome. Instead, we describe the changes in course enrollment after the policy change to inform the broader conversation about high school math pathways.

Tracking and Acceleration in Math Education

The issues surrounding SFUSD's math reforms fit squarely within the broader context of research and policymaking that have shaped math education over the last several decades. Specifically, the new policy rejected two practices that have been the subject of considerable debate and empirical research. First, by keeping students on uniform pathways until 11th grade, the policy aimed to limit the practice of differentiating student course assignments based on academic proficiency (i.e., "tracking"). Second, by moving Algebra I to ninth grade for all students, the reform turned away from a policy of universal early algebra acceleration often known as "Algebra for All" (Boaler et al., 2018; Carranza, 2015; Christopher, 2016; Tintocalis, 2015).

A prominent concern about tracking is that it can reproduce and amplify inequities in learning opportunities. For instance, students in lower-achieving tracks are more likely to be assigned less experienced teachers (Kalogrides & Loeb, 2013). Additionally, the available evidence indicates that, in practice, schools disproportionately assign minoritized students to lower-level tracks when assignment is based on achievement metrics (e.g., test scores) that correlate with socioeconomic status (Conger et al., 2009; Kalogrides & Loeb, 2013; Reardon, 2019). And, when the determinants of course assignment are more discretionary (i.e., based on teacher recommendation), minoritized students are often under-identified for placement in high-achieving pathways (Card & Giuliano, 2016; Grissom & Redding, 2016). In either case, homogenously grouping students by achievement increases within-school stratification along race and class lines (Clotfelter et al., 2021; Conger et al., 2009). The potential consequences of these patterns are highlighted by a body of qualitative and observational studies which conclude that tracking is academically harmful to low-achieving students (Rui, 2009). In an influential case study, students in a school that grouped students heterogeneously by prior achievement outperformed their peers in a pair of tracked comparison schools in terms of both test scores and course progression (Boaler, 2006; Boaler & Staples, 2008). Rui's (2009) metanalysis of cases studies, correlational research and small-scale RCTs also found that *detracking* improved achievement for low-proficiency students.

However, more recent and quasi-experimental research (Ballis & Heath, 2021; Card & Giuliano, 2016; Cohodes, 2020; Collins & Gan, 2013; Cortes & Goodman, 2014; Figlio & Page, 2002) generally finds that tracking positively impacts test score and academic attainment outcomes for students across the achievement distribution. For example, Card and Giuliano (2016) and Cohodes (2020), using regression-discontinuity (RD) designs, find beneficial effects for student placed in high-achieving (e.g., gifted and talented) tracks. More surprisingly, Cortes and Goodman (2014) and Ballis and Heath (2021), find that low-achieving students benefit from placement in lower level and special-education classes. These results run contradictory to theories which predict that less proficient students will experience strong negative peer effects when grouped together in homogeneous classes (Antonovics et al., 2022; Duflo et al., 2011; Lefgren, 2004). The findings are, however, consistent with a parallel series of quasi-experimental studies that have found academic peer effects to be generally modest (Collins & Gan, 2013; Cortes & Goodman, 2014; Lefgren, 2004). Tracking may also benefit low-achieving students by allowing teachers to target their instruction more effectively than they could in a heterogeneously grouped class sections (Antonovics et al., 2022; Collins & Gan, 2013; Duflo et al., 2011).

Yet, even if tracking policies positively impact average academic outcomes, they may carry negative implications for other dimensions of child development. A substantial ethnographic literature reveals cases in which both teachers and students in lower-track classes hold depressed expectations of students' academic potential (Gamoran, 1989; Oakes, 2005). Legette and Kurz-Costes (2021) find that student motivation and sense of belonging in school are negatively related to lower-level track placement, even after controlling for prior achievement. Finally, homogeneously grouping low-achieving students is likely to induce negative *nonacademic* peer effects (i.e., on risky behaviors or attendance), given that the causal literature on peer effects (Sacerdote, 2011) finds that peers have more influence over behavioral rather than strictly academic outcomes.

Notably, most of this tracking literature focuses on "vertical tracking" at lower grade levels (i.e., K through 7). Vertical tracking refers to the within-subject stratification of students into performance-based groups (Domina et al., 2019; Tyson & Roksa, 2016). However, the context for this study includes the widespread but less studied phenomenon of "horizontal tracking" that occurs among students at higher grade levels. Horizontal tracking refers to the sorting of same-grade students across different courses in a contingent sequence (i.e., ninth-grade Algebra I vs. ninth-grade Geometry). International comparisons suggest that delaying meaningful curricular branching (i.e., reducing horizontal tracking) improves average student outcomes by preserving a wider array of educational opportunities for students over their schooling trajectories (Hanushek & Wößmann, 2006). However, for students who would have taken eighth-grade Algebra I in the absence of the policy change, this delay may be consequential in and of itself.

SFUSD's math pathways reform reflected a backlash to the earlier widespread enthusiasm for math course acceleration, most associated with the "Algebra for All" movement. This movement, which made algebra instruction a focal point of math policy in the 1990s, was a response to fears that tracking had created inequitable patterns of access to Algebra I and, as a result, advanced math coursework (Stein et al., 2011). Researchers observed that minoritized students were – and still are – less likely to be enrolled in Algebra I in eighth or even ninth grade than their White peers (Conger et al., 2009; Oakes et al., 1990). Furthermore, a substantial but correlational literature established that early take-up of Algebra I (i.e., in eighth grade) was associated with better test scores and more advanced course-taking in high school (Gamoran & Hannigan, 2000; Stein et al., 2011). In response to this evidence, timely access to algebra coursework was framed as a "civil rights" issue, and delayed access as "gatekeeping" (Moses & Cobb Jr., 2001; Stein et al., 2011; Gamoran & Hannigan, 2000; Oakes et al., 1990). Advocates and researchers promoted universal eighth-grade Algebra I on the assumption that *all* students would see benefits from accelerated exposure to algebra content.

The movement successfully expanded early take-up of Algebra I, but its impacts on student achievement have been mixed (Domina et al., 2015; Stein et al., 2011). Specifically, quasi-experimental studies have consistently found that, rather than opening college-preparatory pathways for students who would have otherwise been placed in lower-level tracks, low-proficiency students are negatively or negligibly influenced by early acceleration. Using a difference-in-differences strategy, Clotfelter et al., (2015) find that early aceleration had "unamibiguously negative" consequences for lower-achieving students, while modest benefits for high performers led to a net zero policy impact.

California was an early and enthusiastic adopter of math-acceleration policies such as “Algebra for All.” In 1997, the state revised its standards to recommend all eighth graders be enrolled in Algebra I. Two years later the Public-School Accountability Act (PSSA) added penalties for schools who continued to enroll eighth graders in pre-algebra classes. By 2009, 51% of all California eight graders were enrolled in Algebra I, up from 16% in the year PSSA was passed. A study by Domina et al., (2015) found that California’s initiative caused overall declines in average tenth grade achievement (Domina et al., 2015). The state adoption of the California CCSS, which promote instruction that integrates pre-algebra and algebra content throughout middle school (CDE, 2015), devolved greater flexibility over acceleration policies to school districts. Regression-discontinuity (RD) studies based on the varying test-score thresholds used in California school districts to identify students for acceleration (Lafortune, 2018; McEachin et al., 2020) find that its impact varies for students at different positions in the achievement distribution. These results replicate the findings in Clotfelter et al. (2015) that acceleration is benign or beneficial for high-achieving students but negatively impacts low-proficiency students. Taken together, these studies present evidence that academically equipped students are more likely to progress through a college-preparatory math pathway and see higher test scores, when assigned to eighth-grade Algebra I.

In motivating their math pathways reform, SFUSD articulated the view that math acceleration was not an evidence-based practice. For example, in Board testimony invited by SFUSD Superintendent Richard Carranza, education researcher Alan Schoenfeld stated that the previous acceleration policy was built on an incorrect “assumption that what counts is procedural mastery rather than deep understanding.” However, the results of a policy to reverse acceleration universally and at scale have yet to be quantitatively studied. Because the SFUSD math-pathways reform did eliminate acceleration (i.e., at least through middle school) and attenuated horizontal tracking, it provides important new evidence relevant to the broader literature on math education policy and practice described here.

A High School Mathematics Pathways Reform

In February 2014, the SFUSD school board unanimously approved a proposal put forward by Superintendent Richard Carranza for a dramatic and ambitious restructuring of the District’s math course pathways. The reform made a major change to math sequencing by removing Algebra I as an enrollment option for eighth graders within the District. A belief that current District practices had led to inadequate and inequitable student preparation in algebra motivated this design change (SFUSD, 2014). The Superintendent’s proposal pointed out that very few students were making on-time progress through the current math sequence: across the 2011-12 and 2012-13 school years, only 19% of tenth graders (and only one percent of Black tenth graders) had both passed the state math assessment and not repeated math coursework. The newly created math sequence would group students together in the same math classes until a “decision point” after 10th grade when students could choose to accelerate (SFUSD, 2014).

District advocates framed this reform as a necessary corrective to a status quo that featured “early acceleration” into eighth grade Algebra I and math curricula that were “mile-wide and inch-deep” (SFUSD Board, 2014). Under the new policy, all students would also follow a Common Core-aligned program of studies through eighth grade that would be paced to encourage deep thinking and the development of strong conceptual mathematical foundations. Furthermore, the reform intended to delay the emergence of academic stratification until students were old enough to personalize their coursework in service of their future goals (Boaler et al., 2018; Carranza, 2015). And, unlike math acceleration in middle school, which tends to formalize tracks based on prior achievement or other externally imposed criteria, these acceleration pathways were open to students who had passed the pre-requisite courses. The most common of these later acceleration options came in 11th grade when SFUSD offered students the option to enroll in a "compression course" that combined Algebra II and Pre-Calculus topics into a single-block year-long class (Carranza, 2015). Tenth graders were also able to accelerate by "doubling up" in Geometry and Algebra II during their academic year, although this option was not taken up as widely as the compression course.

SFUSD implemented this reform for the cohort of students who entered high school in the fall of 2015. Some parents opposed the removal of Algebra I from middle school (Christopher, 2016; Loveless, 2022; Tintocalis, 2015; Tucker, 2015). They argued the new policy unjustly disadvantaged students who were "super-smart" or "ambitious" "whiz kids" (Christopher, 2016; Tintocalis, 2015; Tucker, 2019). Meanwhile, the District's African American Parent Advisory Council submitted a letter to the Board of Education expressing support for the policy, describing it as "rais[ing] expectations for all students while effectively eliminating racially biased tracking" (African American Parent Advisory Council, 2015).

Proponents of the policy change encouraged sceptics to consider the Algebra I delay in the complex context of curricular innovation that followed the rollout of the CCSS (Carranza, 2015; Christopher, 2016). Specifically, the redesigned California eighth grade math class introduced students to more rigorous content, including algebra topics, than a pre-CCSS integrated eight grade math course would have (CDE, 2015; Christopher, 2016). Some districts responded to this scope and sequence change by compressing content across middle school courses so that eighth graders could still enroll in Algebra I. SFUSD opted to instead enroll all students in the unabridged Common Core-aligned middle school sequence and define the formal pathways for acceleration (i.e., the compression course) in later grades. This approach aligned with the CDE's warning that "decisions to accelerate students into the Common Core Standards for higher mathematics before ninth grade should not be rushed" (CDE, 2015). Even so, one parent lamented this reform as promoting a "cookie-cutter approach" to education and feared her son might "lose his engagement in school because it's not moving at a fast enough pace for him" (Tintocalis, 2015). This response is consistent with an established literature on the strong preference for targeted acceleration (i.e., tracking) among – at least some – parents (Fu & Mehta, 2018; Kariya & Rosenbaum, 1999; Wells & Serna, 2010).

Another concern of this approach highlighted by critics was that, without the option to accelerate in eighth grade by compressing the California CCSS middle school curriculum, enrolling in calculus before college would require that students compress five courses (i.e., Algebra I, Geometry, Algebra II, Pre-Calculus and AP Calculus) into the four years of high school. Notably, while the University of California recommends that students intending to pursue study in a STEM field take four years of high school math, they do not specifically privilege calculus over a precalculus or statistics course (Ford, 2022). Parents and counsellors tend to view calculus as more critical to college-admissions success than admission officers say it is (Schwartz, 2022).

In the years following the policy's introduction, advocates on both sides of this reform have claimed that student achievement data support their position. Supporters have pointed to a decline in course-repetition rates and a purported broadening in advanced course access among minoritized students (Boaler et al., 2018; Boaler & Schoenfeld, 2018; Sawchuk, 2018; Tucker, 2019). Failure rates for

Algebra I did drop from approximately forty percent to single digits following the reform (Boaler et al., 2018). However, a requirement that students pass an end-of-course exam to receive Algebra I credit was simultaneously removed, which critics argue has not been properly disentangled from the impact of the pathway reform (Mo, 2021). Opponents have also critiqued the District's definition of "advanced" for including the Algebra II/Precalculus compression course whose precalculus content is not recognized by the state higher-education system (Loveless, 2022; Mo, 2021). The District designates this as an "advanced course" because it includes content above Algebra II. However, the University of California classifies it as an Algebra II course for post-secondary articulation (Regents of the University of California, 2018). This indicates that California's public universities do not consider this course's content sufficient to exempt students from precalculus prerequisites.[1]

Adding further complexity, the implementation of the policy has not been static across cohorts. While an original intent of the reform was to keep students largely on a uniform pathway until 11th grade, new and earlier acceleration options introduced were soon made available.[2] In addition to the "compression course" taken mostly by juniors, many students from the Class of 2020 onward have accelerated by enrolling in summer-school Geometry immediately following their freshman year. We consider the 'on the ground' evolution of the policy in our analysis and discussion of results.

Data and Methodology

We base our analysis on longitudinal, student-level data for six cohorts of SFUSD high-school students that spanned the introduction of the math pathways reform. San Francisco Unified School District (SFUSD) provided access to these data under the aegis of a Researcher-Practice Partnership (RPP). These data include student identifiers, demographic data, and transcript data including course identifiers, credits attempted, credits earned, and the letter grade received. We observe 23,309 unique students; approximately 4,000 students for each of the six cohorts we examine. Appendix Table 1 presents descriptive statistics of the racial and ethnic composition of these students. Asian or Pacific Islander students compose the largest racial/ethnic group in SFUSD (45%), followed by Hispanic students (26%).

For our main analysis, we define six cohorts based on the expected graduation year of first-time ninth graders (i.e., those expected to be in the graduating classes of 2016 through 2021).[3] We use this cohort definition because entering ninth graders are conceptually the "intent to treat" (ITT) units who experienced the cohort-specific changes in SFUSD's mathematics pathways. We note that this construction excludes students who transfer into the District after ninth grade (typically, less than 10 percent of a senior class) while including students who are not necessarily observed graduating in the District. We consider the empirical relevance of this baseline-focused cohort definition by reproducing our main findings (Appendix Figures A2, A3, and A4) when defining cohorts based instead on the

[1] Compared to the California CCSS for Mathematics Precalculus Overview, the scope and sequence of the SFUSD compression course excludes units on conic sections, vector and matrix quantities, and the study of polar coordinate systems is optional.

[2] An exception was also made for students who attended eighth grade outside of SFUSD. These students could enroll in Geometry as ninth graders if they passed an assessment called the Math Validation Test (MVT).

[3] We note that the COVID-19 pandemic began in March 2020, after the Class of 2020 had already enrolled in a slate of courses and thus their enrollments are not affected by the pandemic. For the Class of 2021, though, it is possible that the pandemic affected their decisions to enroll in particular coursework and led them to enroll in lower-level courses, thus tamping down the effect of the pathways change. Our findings do not bear out this concern: the Class of 2021 generally enrolled in more rigorous mathematics coursework than the Class of 2020.

graduation years of first-time seniors (i.e., including transfers in while excluding students who left the District). We find that our conclusions are effectively unchanged.

The accurate identification of math courses in the student-level transcript data is critical for our analysis. Course articulation across schools and districts often presents a challenge to researchers because naming conventions and rigor for ostensibly identical courses are not standardized. These issues are attenuated for our analysis because we consider course-taking within a single district. Furthermore, we collaborated directly with SFUSD staff to construct and validate a list of all math courses observed in the transcript data during this time frame and to categorize these course identification numbers into categories like Algebra I or Pre-Calculus. First, we retained all course observations for which the course title, id, or category indicated that it was a math course. We used these fields to introduce common groupings (e.g., "CCSS Geometry", "Geometry 1" and "Geometry A" are collapsed into the category "Geometry"). SFUSD verified the accuracy of these course-category matches and provided specific feedback on observations we had not be able to code with high confidence. Categories were finalized after a second round of collaborative coding and review. We exclude courses taken outside of SFUSD and transferred into the District, because these courses are coded inconsistently and thus cannot be categorized. We also note that, when the measured racial/ethnic identity of a student changes over time (i.e., less than two percent of students), we rely on the most recent, non-missing value.

Our main descriptive analyses effectively rely on varied comparisons of conditional means defined for different dimensions of math course-taking and performance and by particular traits such as graduation cohorts (e.g., pre- and post-reform), grade levels, and the race/ethnicity of the student. Following recent federal guidance on conducting descriptive studies in education, we eschew foregrounding statistical inferences about the changes observed in these data (Loeb et al., 2017). However, because of the likely interest in such inferences, we also report several regression-based tests of statistical significance in the appendix. These inferences compare both the three pre-reform to the three post-reform cohorts (Table A3) as well as the single cohorts immediately before and after the reform (Table A4).

Results

Course Enrollment by Grade

In Figure 1, we present the course-taking pathways of students by grade and their expected graduation cohort. For example, Panel A illustrates how ninth grade math course-taking differed across cohorts that entered high school just before and after the policy change (i.e., the pre-reform graduation cohorts of 2016, 2017, and 2018 and the post-reform cohorts of 2019, 2020, and 2021). Prior to the reform, most ninth graders enrolled in Geometry (e.g., 52% in the 2018 cohort) or Algebra I (e.g., 37% of the 2018 cohort) and these enrollment patterns were quite stable. Consistent with the policy intent, we observe a clear and dramatic discontinuity beginning with the Class of 2019—the first cohort subject to the reform that made Algebra I the default grade-9 course and unavailable to District students in earlier grades. Geometry enrollment fell by 45 percentage points to seven percent while enrollment in Algebra I jumped 53 percentage points to 90%. This sharp change in grade-9 math enrollment attenuated slightly for the 2020 and 2021 cohorts who made more extensive use of acceleration options (e.g., testing directly into Geometry or taking Geometry in the summer).

Panel B of Figure 1 illustrates a similarly large change in math enrollment among tenth graders. For example, comparing the graduation cohorts of 2018 and 2019, Geometry enrollment increased by 38 percentage points (i.e., from 40% to 78%) while exclusive enrollment in Algebra II decreased by 33 percentage points (i.e., from 38% to 5%). As in Panel A, we also observe these changes attenuated somewhat for the 2020 and 2021 cohorts who made more use of acceleration options.

Among 11th graders (Panel C), enrollment in Algebra II increased between 2018 and 2019 (i.e., 40% to 54%) while enrollment in Precalculus fell (i.e., 41% to 16%). We also observe, beginning with the 2019 cohort, roughly 20 percent of 11th graders enrolled in the newly scaled-up "compression" course combining Algebra II and Precalculus. In the 2020 and 2021 cohorts, we observe students who had accelerated in prior years – by taking the math validation exam upon high school entry, enrolling in Geometry over the summer after ninth grade, or enrolling in Geometry and Algebra II concurrently – enrolling in standalone Pre-Calculus as 11th graders.

Finally, panel D illustrates the changing patterns in 12th-grade math enrollment. Between the 2018 and 2019 cohorts, participation in AP Calculus fell by six percentage points (i.e., from 30% to 24%). Enrollment in the year-long Precalculus course jumped by 10 percentage points for the 2019 cohort but dropped back to its pre-reform baseline among the 2021 cohort. Notably, a modest but distinct increase in AP Statistics and a trend towards enrollment in "Probability and Statistics" also characterizes the post-reform cohorts. We also note that 12th-grade math enrollment was not required for graduation in SFUSD and that we observe only small changes in the share of SFUSD 12th graders taking no math courses (i.e., roughly one in four). Because they did not enroll in a math course, these students are not represented as a line in this figure (though they are present in the denominator).

Cumulative Course Enrollment

Figure 1 illustrates the dramatic changes in math enrollment among all SFUSD students following the pathways reform (e.g., delays in taking Algebra I, Geometry, and Algebra II, later attenuated by increased enrollment in acceleration options). However, as noted above, the imperative to increase the enrollment of Black and Hispanic students in advanced math courses was a central motivation for this reform (Carranza, 2015). In Figure 2, we illustrate how enrollment in specific advanced math courses at any time in high school varied across cohorts both among all students as well as among the four largest racial/ethnic groups in the District (i.e., Asian or Pacific Islander, White, Hispanic, and Black).[4]

These data underscore the stark racial/ethnic disparities that motivated the pathways reform. For example, Panel A presents data on Precalculus enrollment and shows that—both before and after the reform—White and Asian students in SFUSD enroll in Precalculus at rates roughly two to four times higher than their Black and Hispanic peers.[5] However, these data also suggest some reductions in these gaps during the post-reform period. Specifically, in the Class of 2018, 13% of Black students enrolled in Pre-Calculus at any point in their high school career; in the Class of 2019, 20 percent did (a 55% increase), though large racial and ethnic enrollment gaps persisted. We also observe a small

[4] In the appendix, we present corresponding regression-based estimates of statistical significance based on comparing the entire pre- and post-reform cohorts (Table A3) as well as the cohorts just before and after the reform (Table A4).

[5] We define Precalculus participation here to include the Algebra II/Precalculus compression course though it is not recognized by the state system of higher education as meeting Precalculus requirements. In Appendix Figure A1, we show how participation in yearlong vs. compressed versions of Precalculus varied starkly across cohorts.

overall increase in the percentage of students enrolling in Pre-Calculus (53% in the Class of 2018 and 55% in the Class of 2019).

In Figure 2 Panel B, we present access to Probability and Statistics. Overall enrollment in Probability and Statistics decreased after the policy change from 12% to 10 %. It then rebounded in subsequent years, with 17% of the Class of 2021 enrolling in the course. The course became more popular across all racial/ethnic groups over the observed time span. Black students enrolled in the Probability and Statistics at the highest rate, while Asian/Pacific Islander students enrolled in AP Statistics at the highest rate. This reversal of expected racial/ethnic enrollment gaps may reflect the differences in course offerings provided by SFUSD high schools; in SY 2020-21, the six high schools with the highest percentages of Asian/Pacific Islander students all offered AP Statistics while only two of the six high schools with the highest percentages of Black students offered that course.

Figure 2 Panel C presents access to AP Calculus and shows that the percentage of students enrolling in Calculus decreased after the policy's implementation by six percentage points (a 21% decrease). Again, we observe large gaps in course enrollment by racial/ethnic subgroups and a lack of access for Black and Hispanic students. These trends persist before and after the policy, with less than 10% of Black and Hispanic students enrolled in Calculus for every year in our sample.

While enrollment in AP Calculus declined, enrollment in AP Statistics increased slightly by one percentage point. Figure 2 Panel D illustrates the broader trend: AP Statistics enrollment was increasing prior to the policy's implementation and continued to do so after the policy's implementation. This enrollment increase is seen for all racial/ethnic sub-groups except Black students.

Figure 2 Panel E allows us to combine course-taking in AP Calculus and AP Statistics to visualize what percentage of an expected graduation cohort had taken at least one AP math course before the end of 12th grade. We observe a five-percentage point (or 15%) decrease in the percent of students enrolling in an AP math course immediately after the policy's implementation. As more students enrolled in acceleration options, AP math enrollment was restored to its 2018 levels.

In Figure 2 Panel F, we present the percentage of students not enrolling in math in 12th grade. Though a fourth year of math is not required for admission to the University of California or California State University systems, it is recommended and thus observers would hope to see the percentage of students not enrolling in math declining. Additionally, value of "recency" in content exposure suggests that enrolling in a 12^{th} grade math course may improve post-secondary math achievement (Bracco et al., 2020). This is what we observe: in the Class of 2018, 25% of students chose to not enroll in 12th grade math whereas in the Class of 2019, 23% did.

Credit Attainment

Figures 1 and 2 presented enrollment patterns. But, another explicit goal of the policy was to increase credit attainment in math by building a stronger foundation in middle school. SFUSD leadership hoped the policy would lead to more students not just enrolling but also earning credit in college preparatory math courses (Carranza, 2015). In Figure 3, we present the share of a graduation cohort earning a full year of credit in a course at some point during high school.[6]

Though enrollment and credit attainment are linked, they are not necessarily the same. If growing enrollment pushed students into courses they were not ready for, then credit attainment would stay stable. If enrollment grew and the preparation of course-takers remained stable, then credit attainment would increase by approximately the same degree as enrollment. If enrollment grew and preparation for the courses improved (perhaps through curricular change), then credit attainment would increase by a larger degree than enrollment. This same logic holds in the reverse.

In Figure 3 Panel A, we see that the share of the graduation cohort earning a full year of credit in Pre-Calculus increased slightly from 49% in the Class of 2018 to 51% in the Class of 2019. This is consistent with our finding that Pre-Calculus enrollment increased by two percentage points and thus shows that the preparation of course-takers for the material did not change due to the policy. Large gaps in credit attainment still persist by racial/ethnic sub-group.

Figure 3 Panel B shows that the share of the graduation cohort earning a full year of credit in Probability and Statistics decreased in the immediate post-policy year by one percentage point and then increased again. This mirrors what we observed in enrollment. Figure 3 Panel C shows that the share of the graduation cohort earning a full year of credit in AP Calculus declined after the policy implementation, which is consistent with declining enrollment in the course over this time period. This drop is steepest in 2019, when the policy is first implemented, and then credit attainment partially recovers (as enrollment did) when the District expands its acceleration options.

Figure 3 Panel D shows credit attainment in AP Statistics and shows attainment increasing overall and for all sub-groups except Black students over this time horizon. This is consistent with the finding that enrollment in the course increased over this time period.

Finally, Figure 3 Panel E shows that credit attainment in AP Math also follows its enrollment trend, decreasing in the initial post-policy period and then rising back to 2018 levels by 2021.

Discussion

In this study, we illustrate how math course-taking patterns shifted for students in SFUSD after the implementation of a substantial math pathways reform that situated Algebra I enrollment in ninth grade. In short, when enrollment in Algebra I in ninth grade became the norm, so did tenth-grade enrollment in Geometry as well as delaying Algebra II and Pre-Calculus to later years. We also observe a modest post-reform increase in Precalculus enrollment (i.e., defined to include the Algebra II/Precalculus compression course) with the largest gains among Black students as well as a growing take-up of courses in probability and statistics. Notably, we also find that the introduction of the reform coincided with a sharp reduction in AP Calculus enrollment that was particularly concentrated among Asian/Pacific-Islander students. We also observe a continuation of the trend of increasing AP Statistics enrollment before the policy change. Finally, we observe that large ethnoracial gaps in AP math course-taking did not decrease after the policy change.

[6] A full year of credit is defined as 10 credits; students earn 10 credits if they earn a D or above in both semesters of a course and must have at least 30 credits of math in order to graduate from SFUSD.

This policy had two significant goals. First, the policy aimed to reduce tracking in ninth and tenth grade mathematics. Towards that end, in the first year of the policy, we observe broad success with 90% of ninth grade students enrolled in Algebra I and 78% of tenth grade students enrolled in Geometry, thus creating more heterogeneous peer groups. Notably, such "vertical detracking" was achieved through delaying a substantial share of students from taking Algebra I and Geometry a year earlier. Second, the policy aimed to increase enrollment of historically marginalized groups in advanced math courses. In the first year of the policy, we observe that the policy failed to achieve this goal with enrollment in AP math declining by 5 percentage points (52%) for Black students and remaining stable for Hispanic students. Finally, the policy aimed to achieve both these goals (i.e., a reduction in tracking in early high school grades and an increase in advanced math course-taking for historically underrepresented groups) without dampening the academic achievement of other groups of students. By this definition, the first year of the policy failed with large declines in AP math enrollment for White and Asian/Pacific Islander students. Our evidence is consistent with the hypothesis that delaying Algebra I until ninth grade made it difficult for some students to complete the sequence of course prerequisites that would position them to take AP Calculus before graduating.

In the years following the initial policy change, the District made new acceleration options available (e.g., summer Geometry) and spread information about how to access options that had already existed (e.g., the Algebra II/Precalculus compression course). These options led to increases in tracking in ninth and tenth grade, though tracking still remained far below the pre-policy years, and allowed more students to access advanced math courses. In fact, participation in AP math among the graduating class of 2021 (our most recent class in the data) was nearly equal to that for the graduating class of 2018 (the last pre-reform cohort), demonstrating that the policy ultimately did not increase access but also did not restrict it. In addition, in this study, we observe only course enrollment and credit attainment and cannot say how longer-term outcomes (such as academic achievement in math, enrollment in math courses in college, the selection of STEM majors, student self-concept as math learners) changed with this policy.

We conclude with two broader observations about our findings. First, large ethnoracial gaps in advanced math course-taking motivated this reform but did not change in the post-reform period. In the post-policy period, the percent of Black students enrolling in any AP math course has remained statistically significantly indistinguishable from the pre-policy period while Hispanic student enrollment in advanced math increased by 1 percentage point. Given that acceleration in the post-policy period was, conditional on passing the prior course, based solely on student request (i.e., not on test scores or counsellor recommendation), this underscores questions about how the District's course-offering and selection processes support equitable learning opportunities.

Second, these findings are situated within larger, ongoing debates about the propriety of calculus and "data science" courses for contemporary high-school graduates. In particular, calculus has been historically viewed as a requirement for admissions to competitive colleges and as a necessary high school stepping stone into careers in STEM (Bressoud, 2021). College counselors in public high schools still view it that way with 87% reporting that they believe "calculus gives applicants an edge in the admissions process." However, this perception appears misaligned with survey responses from admissions counselors themselves who agree with that statement only 53% of the time (Schwartz, 2022). Commentators have also argued that courses like probability or statistics, are underrepresented in current secondary programs of study (Levitt & Severts, 2022). These considerations about the varied educational goals associated with reforming math pedagogy provide an important context for framing the possibilities and challenges of initiatives like the one examined here.

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Figure 1. Course Access by Grade

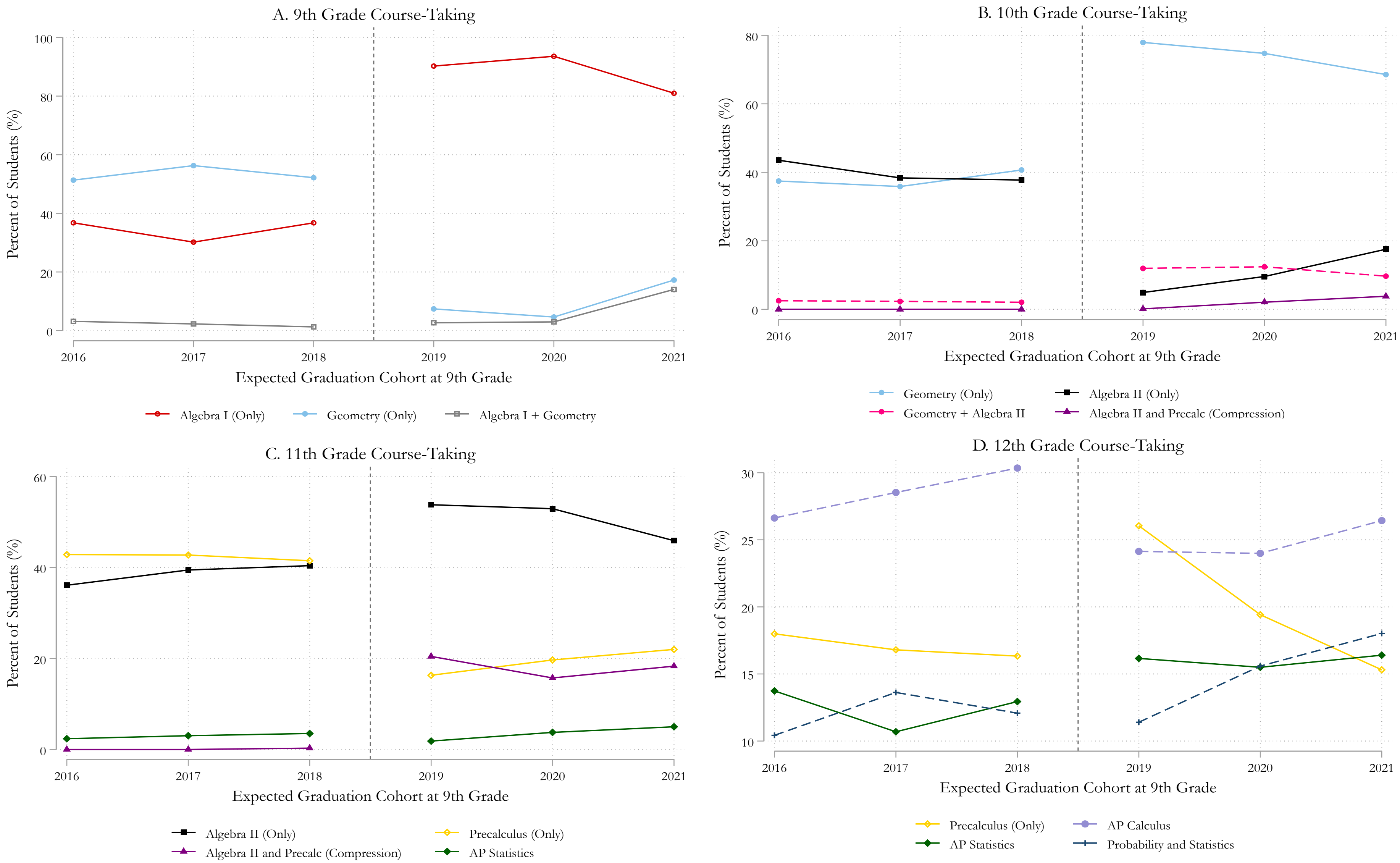


Figure 2. Access to Advanced Courses by Race/Ethnicity

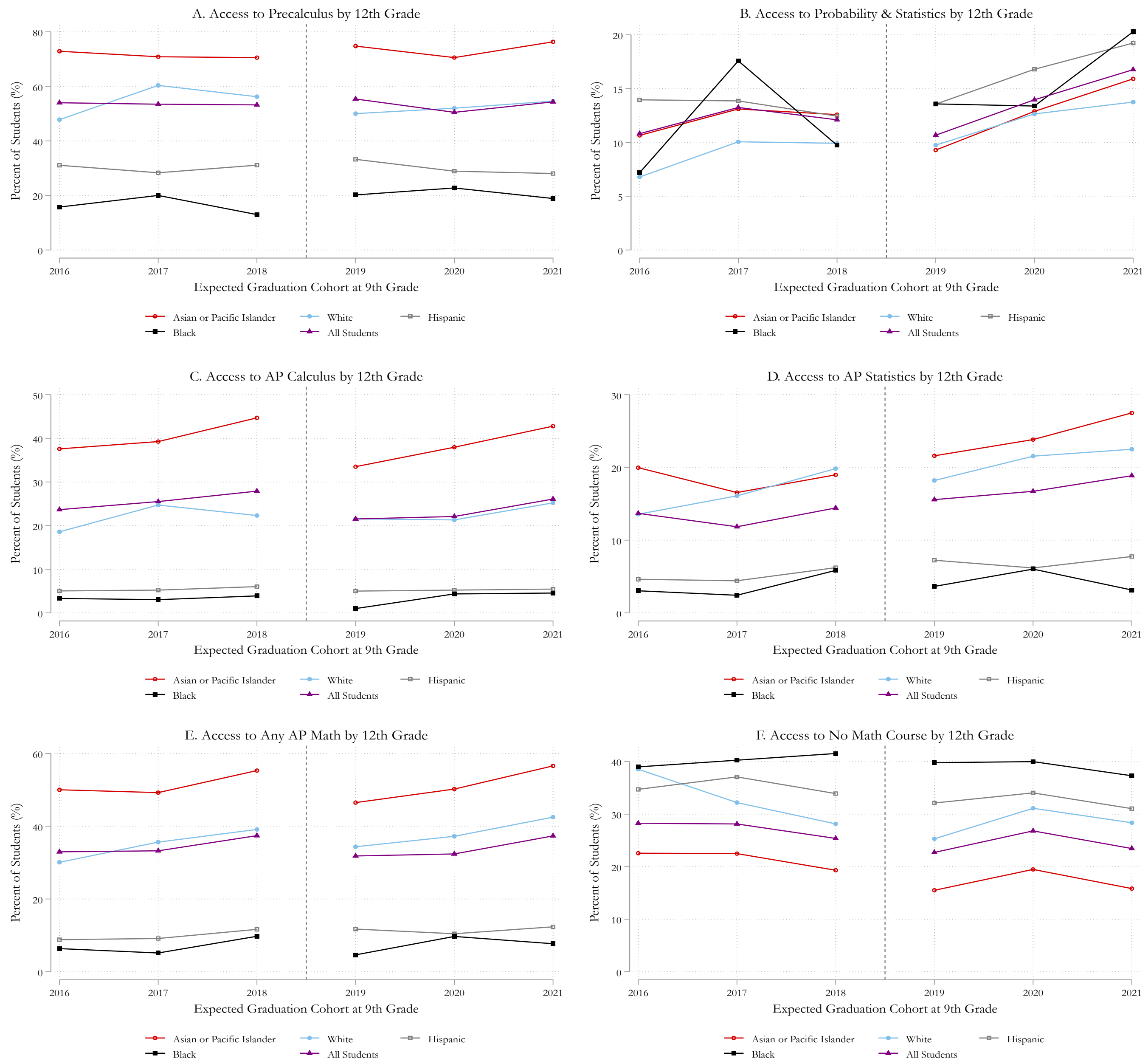


Figure 3. Success in Advanced Courses by Race/Ethnicity

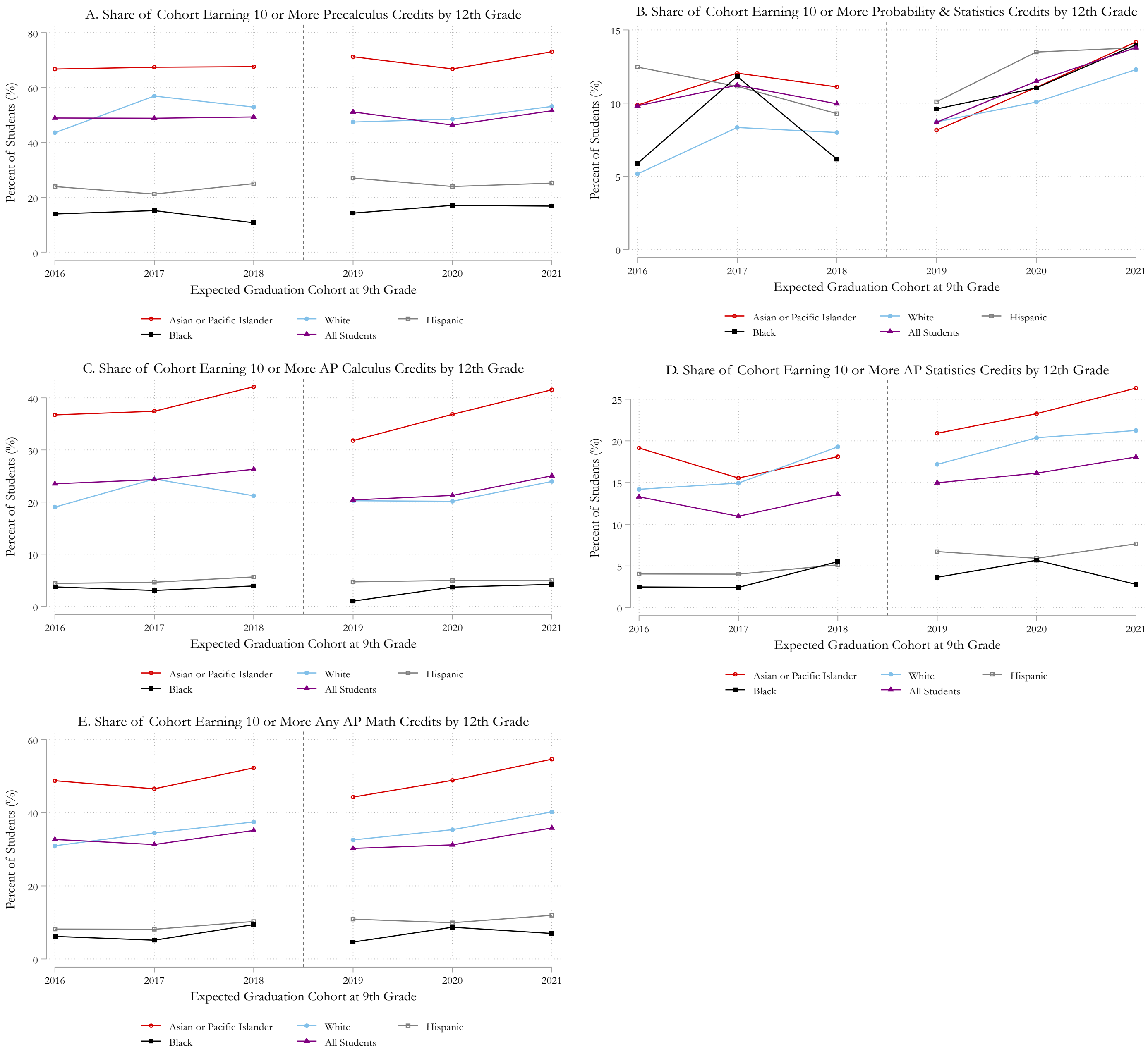


Table A1: Racial/Ethnic Composition of SFUSD High School Students by Class

	2016	2017	2018	2019	2020	2021
Asian or PI N	1954	1802	1828	1755	1599	1622
percent	49.71%	46.81%	47.26%	45.79%	40.74%	41.57%
Black N	362	330	308	302	299	286
percent	9.21%	8.57%	7.96%	7.88%	7.62%	7.33%
Hispanic N	953	996	1013	982	1149	1045
percent	24.24%	25.87%	26.19%	25.62%	29.27%	26.78%
Multiracial N	68	74	90	101	183	194
percent	1.73%	1.92%	2.33%	2.64%	4.66%	4.97%
Native American N	22	28	12	24	14	9
percent	0.56%	0.73%	0.31%	0.63%	0.36%	0.23%
White N	339	348	363	390	427	480
percent	8.62%	9.04%	9.38%	10.17%	10.88%	12.30%
Decline to State N	233	272	254	279	254	266
percent	5.93%	7.06%	6.57%	7.28%	6.47%	6.82%
Total N	3931	3850	3868	3833	3925	3902

Table A2: Math Course-Taking Patterns of SFUSD High School Students by Class

	2016	2017	2018	2019	2020	2021
Took Algebra 1 in 9th Grade: N	1568	1250	1471	3562	3790	3706
percent	39.89%	32.47%	38.03%	92.93%	96.56%	94.98%
Ever Took Pre-Calculus: N	2122	2058	2058	2122	1981	2119
percent	53.98%	53.45%	53.21%	55.36%	50.47%	54.31%
Ever Took Probability & Statistics: N	425	510	468	409	548	654
percent	10.81%	13.25%	12.10%	10.67%	13.96%	16.76%
Ever Took AP Calculus: N	916	982	1079	825	867	1018
percent	23.30%	25.51%	27.90%	21.52%	22.09%	26.09%
Ever Took AP Statistics: N	538	456	558	597	656	736
percent	13.69%	11.84%	14.43%	15.58%	16.71%	18.86%
Ever Took AP Math: N	1296	1280	1447	1220	1271	1457
percent	32.97%	33.25%	37.41%	31.83%	32.38%	37.34%
Total N	3931	3850	3868	3833	3925	3902

Table A3. Difference in Average Course Enrollment Between Pre- and Post- Policy Cohorts

Course	All Students	Asian or Pacific Islander	Black	Hispanic	White
Precalculus	-0.0019	0.0247**	0.0433*	-0.0020	-0.0251
p-value	0.7973	0.0045	0.0149	0.9311	0.2116
AP Calculus	-0.0243***	-0.0249*	-0.0013	-0.0021	0.0092
p-value	0.0000	0.0107	0.8872	0.7242	0.6367
AP Statistics	0.0374***	0.0569***	0.0058	0.0193**	0.0432**
p-value	0.0000	0.0000	0.5824	0.0012	0.0081
Probability and Statistics	0.0177***	0.0053	0.0427**	0.0320***	0.0323*
p-value	0.0001	0.3674	0.0074	0.0006	0.0131
No 12th Grade Math	-0.0291***	-0.0458***	-0.0124	-0.0277*	-0.0441*
p-value	0.0000	0.0000	0.6580	0.0402	0.0243
Any AP Math	-0.0068	-0.0052	0.0033	0.0157*	0.0327
p-value	0.2654	0.6633	0.8277	0.0380	0.1220
District-Defined Advanced Math	0.0174**	0.0230***	0.0679**	0.0306*	0.0525**
p-value	0.0050	0.0009	0.0022	0.0156	0.0083
N	23,309	10,558	1,887	6,137	2,347

Notes: This table summarizes comparisons of course enrollment for cohorts preceding (i.e., classes of 2016, 2017, 2018) and following (i.e., classes of 2019, 2020 and 2021) changes to SFUSD's Algebra assignment policy. Each cell displays the mean difference in post- versus pre- policy change enrollment by graduaton cohort defined at 9th grade entry. P-values for a post-hoc joint hypothesies test comparing the equivalence of post- and pre- policy coefficients are generated by a regression of the outcome on a set of cohort indicator variables for each subgroup-outcome comparison. In the underlying regressions, standard errors are robust and the baseline cohort (i.e., the class of 2016) is the omitted group. + p<.1, * p<0.05, ** p<0.01, *** p<0.001.

Table A4. Difference in Average Course Enrollment Between the 2018 and 2019 Graduating Cohorts

Course	All Students	Asian or Pacific Islander	Black	Hispanic	White
Precalculus	0.0216+	0.0424**	0.0721*	0.0214	-0.0620+
	(0.0114)	(0.0149)	(0.0301)	(0.0209)	(0.0364)
AP Calculus	-0.0637***	-0.1119***	-0.0290*	-0.0103	-0.0078
	(0.0098)	(0.0162)	(0.0124)	(0.0102)	(0.0302)
AP Statistics	0.0115	0.0261+	-0.0220	0.0102	-0.0163
	(0.0081)	(0.0134)	(0.0172)	(0.0112)	(0.0287)
Probability and Statistics	-0.0143*	-0.0329**	0.0384	0.0112	-0.0017
	(0.0072)	(0.0104)	(0.0260)	(0.0151)	(0.0217)
No 12th Grade Math	-0.0267*	-0.0382**	-0.0175	-0.0180	-0.0284
	(0.0105)	(0.0130)	(0.0491)	(0.0238)	(0.0354)
Any AP Math	-0.0558***	-0.0881***	-0.0510*	0.0007	-0.0476
	(0.0108)	(0.0166)	(0.0208)	(0.0144)	(0.0352)
District-Defined Advanced Math	0.0009	-0.0084	0.0553	0.0287	-0.0055
	(0.0107)	(0.0119)	(0.0376)	(0.0223)	(0.0344)
N	7,701	3,583	610	1,993	753

Notes: This table summarizes comparisons of course enrollment for cohorts preceding (i.e., classes of 2016, 2017, 2018) and following (i.e., classes of 2019, 2020 and 2021) changes to SFUSD's Algebra assignment policy. Each cell displays the mean difference in post- versus pre- policy change enrollment by graduaton cohort defined at 9th grade entry. P-values for a post-hoc joint hypotheses test comparing the equivalence of post- and pre- policy coefficients are generated by a regression of the outcome on a set of cohort indicator variables for each subgroup-outcome comparison. In the underlying regressions, standard errors are robust and the baseline cohort (i.e., the class of 2016) is the omitted group. + $p<.1$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Table A5. Difference in Average Course Attainment Between Pre- and Post- Policy Cohorts

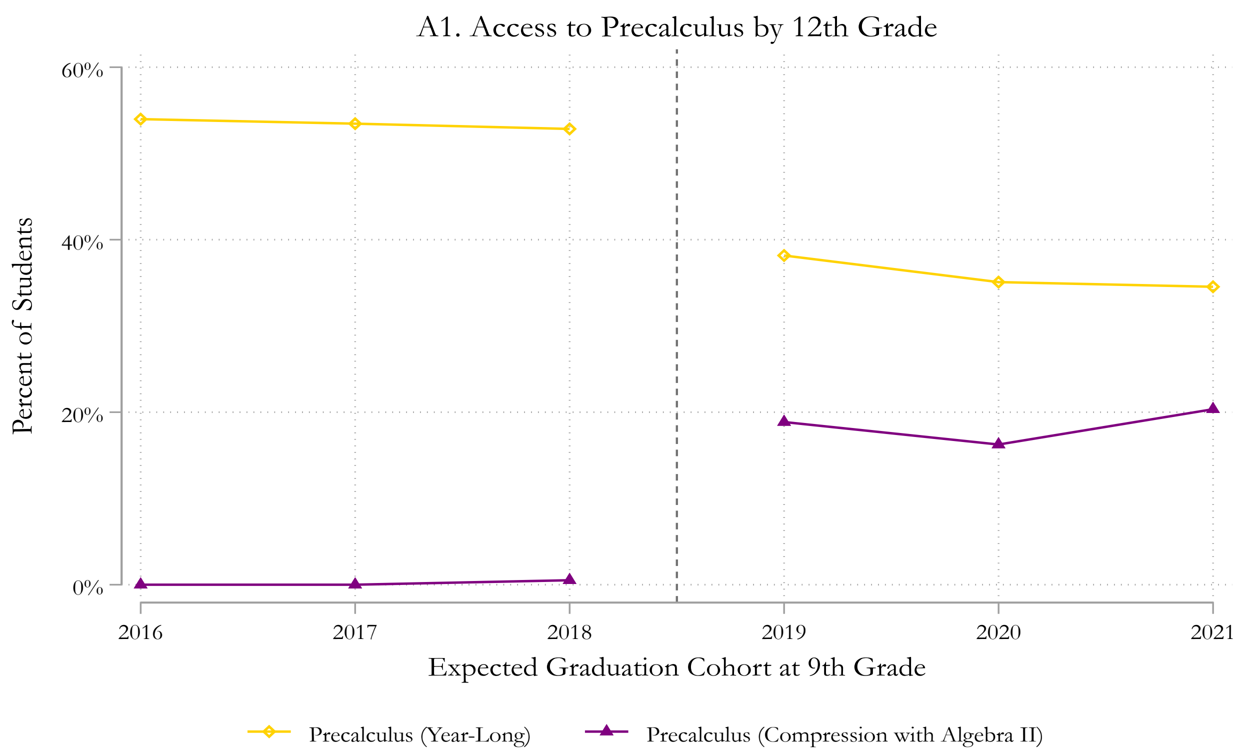
Course	All Students	Asian or Pacific Islander	Black	Hispanic	White
Precalculus	0.0065	0.0315***	0.0269+	0.0195+	-0.0154
p-value	0.3121	0.0006	0.0942	0.0679	0.4934
Probability and Statistics	0.0100*	0.0007	0.0349**	0.0164+	0.0324**
p-value	0.0150	0.8364	0.0095	0.0705	0.0061
AP Calculus	-0.0247***	-0.0214*	-0.0061	-0.0001	-0.0006
p-value	0.0000	0.0319	0.4746	0.9983	0.9514
AP Statistics	0.0379***	0.0580***	0.0062	0.0233***	0.0348*
p-value	0.0000	0.0000	0.5220	0.0001	0.0300
Any AP Math	-0.0062	-0.0006	-0.0010	0.0200**	0.0184
p-value	0.3132	0.9381	0.9021	0.0070	0.3840
N	23,117	10,511	1,848	6,075	2,318

Notes: This table summarizes comparisons of course attainment for cohorts preceding (i.e., classes of 2016, 2017, 2018) and following (i.e., classes of 2019, 2020 and 2021) changes to SFUSD's Algebra assignment policy. Attainment is defined by an indicator variable that is 1 if a student earns full credit (i.e., 10 units) for a course by the end of 12th grade. Each cell displays the mean difference in post- versus pre- policy change enrollment by graduaton cohort defined as 9th grade entry. P-values for a post-hoc joint hypotheses test comparing the equivalence of post- and pre- policy coefficients are generated by a regression of the outcome on a set of cohort indicator variables for each subgroup-outcome comparison. In the underlying regressions, standard errors are robust and the baseline cohort (i.e., the class of 2016) is the omitted group. + p<.1, * p<0.05, ** p<0.01, *** p<0.001.

Table A6. Difference in Average Course Attainment Between the 2018 and 2019 Graduating Cohorts

Outcome	All Students	Asian or Pacific Islander	Black	Hispanic	White
Precalculus	0.0183	0.0361*	0.0352	0.0204	-0.0546
	(0.0114)	(0.0154)	(0.0268)	(0.0197)	(0.0365)
Probability and Statistics	-0.0127+	-0.0296**	0.0343	0.0081	0.0073
	(0.0066)	(0.0098)	(0.0218)	(0.0133)	(0.0202)
AP Calculus	-0.0589***	-0.1033***	-0.0290*	-0.0094	-0.0096
	(0.0096)	(0.0160)	(0.0124)	(0.0099)	(0.0296)
AP Statistics	0.0140+	0.0280*	-0.0188	0.0159	-0.0210
	(0.0080)	(0.0132)	(0.0169)	(0.0106)	(0.0282)
Any AP Math	-0.0492***	-0.0797***	-0.0478*	0.0064	-0.0490
	(0.0107)	(0.0167)	(0.0206)	(0.0138)	(0.0348)
N	7,701	3,583	610	1,993	753

Notes: This table summarizes comparisons of credit attainment for the cohort directly preceding (i.e. class of 2018) and following (i.e., class of 2019) changes to SFUSD's Algebra assignment policy. Sample sizes reflect the combined subgroup counts for those two graduation cohorts, defined at 9th grade entry. Each cell displays the coefficient and robust standard error for a bivariate regresson of an indicator for a student earning full credit for a course (i.e., 10 credits) on an indicator for the 2019 graduating cohort. Robust standard errors are listed in parentheses. + p<.1, * p<0.05, ** p<0.01, *** p<0.001.



A1. Access to Precalculus by 12th Grade
60%
40%
20%
0%
Percent of Students
2016
2017
2018
2019
2020
2021
Expected Graduation Cohort at 9th Grade
Precalculus (Year-Long)
Precalculus (Compression with Algebra II)

Figure A2. Course Access by Grade (Alternative Cohort Definition)

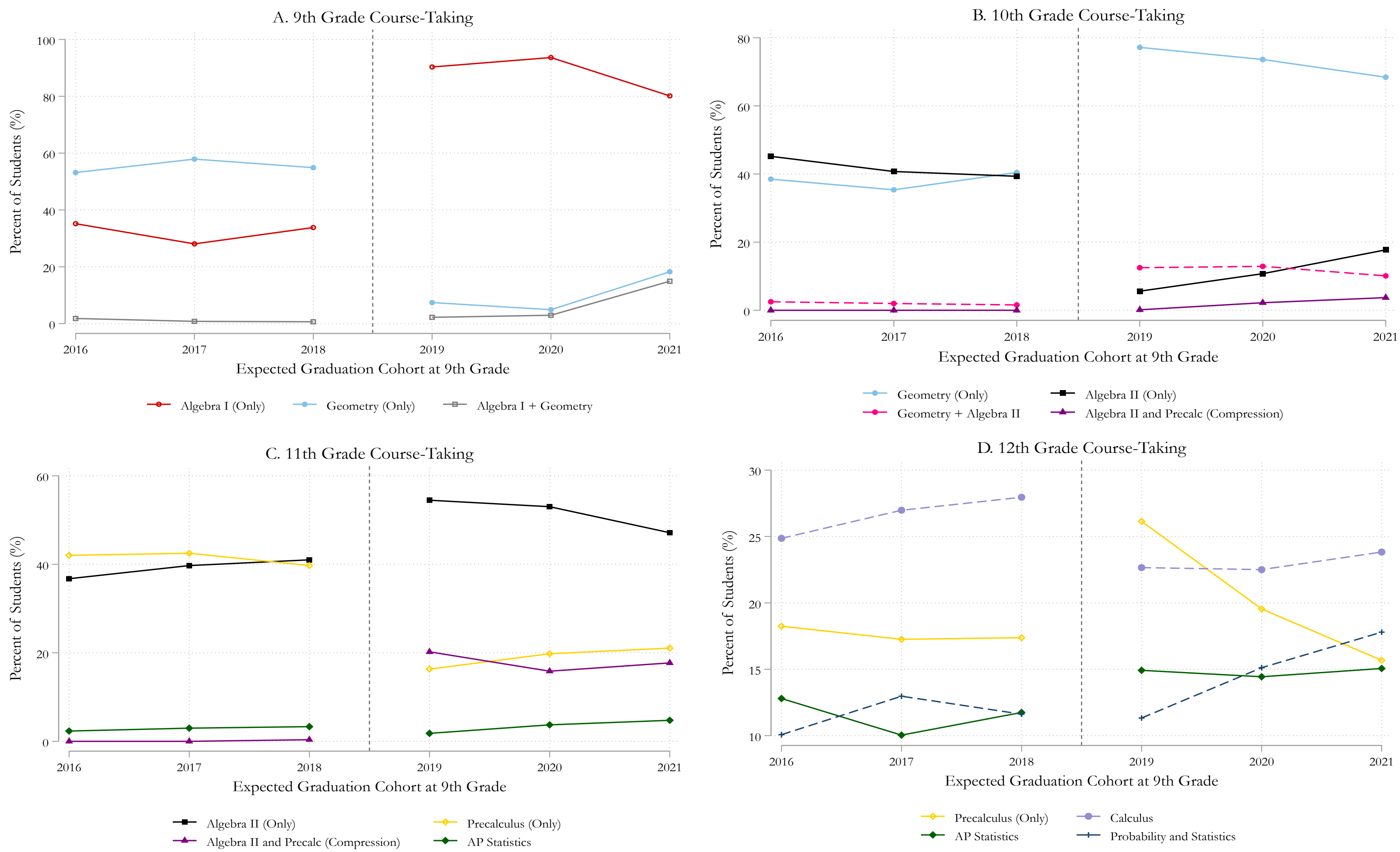


Figure A3. Access to Advanced Courses by Race/Ethnicity (Alternative Cohort Definition)

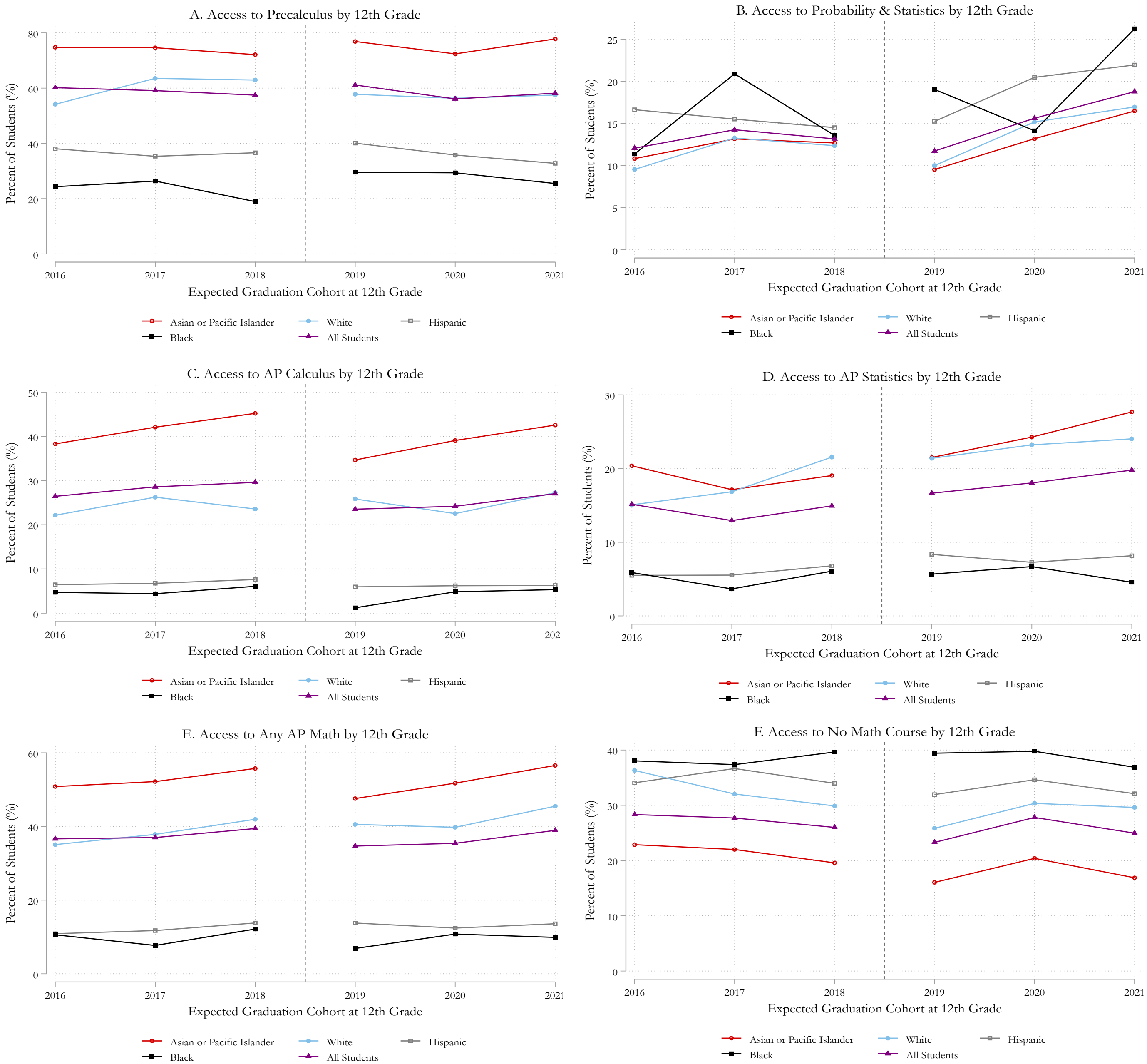


Figure A4. Success in Advanced Courses by Race/Ethnicity (Alternative Cohort Definition)