Seasonal Dynamics of Academic Achievement Inequality by Socioeconomic Status and Race/ethnicity: Updating and Extending Past Research with New National Data

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Abstract

Early studies examining seasonal variation in achievement inequality generally concluded that socioeconomic test score gaps grew more over the summer than the school year, suggesting schools served as "equalizers." In this study, we analyze seasonal trends in SES and racial/ethnic test score gaps using nationally-representative data from the ECLS-K:2011, which includes more school-year and summer rounds than previous national studies. We further examine how inequality dynamics are influenced by the operationalization of inequality. Findings are consistent with a story in which schools initially accelerate relatively lower-achieving groups' learning more so than higher-achieving groups; however, this school-year equalizing is not consistently maintained, and sometimes reverses. When we operationalize inequality as changes in relative position, the reversal of school-year equalizing is more pronounced.

Seasonal Dynamics of Academic Achievement Inequality by Socioeconomic Status and Race/ethnicity: Updating and Extending Past Research with New National Data

The question of whether summer vacation negatively impacts student learning has long been of interest to educators and social scientists (Cooper, Nye, Charlton, Lindsay, & Greathouse, 1996). Of particular concern is whether summer learning rates differ by students' socioeconomic status (SES) or race/ethnicity in ways that contribute to inequalities in academic outcomes. Early studies generally found that SES gaps in literacy grew more over the summer than the school year (Alexander, Entwisle, & Olson, 2001; Heyns, 1978), and scholars concluded from such evidence that schools served as "equalizers" (Alexander et al., 2001; Downey, von Hippel, & Broh, 2004). At the same time, some studies found that gaps in math achievement by SES did not grow over the summer (Cooper et al., 1996), and conclusions were mixed as to whether summer vacation negatively impacted test score gaps by race/ethnicity (Burkam, Ready, Lee, & LoGerfo, 2004; Cooper et al., 1996; Heyns, 1987; Murnane, 1975).

Scholars have recently questioned the findings of some early studies due to psychometric concerns (von Hippel, Hamrock, & Kumar, 2016). Additionally, researchers are calling attention to the ways in which applying different methodological strategies to these topics changes the research question and the conclusions drawn (Quinn, 2015a). Within this context, we contribute to the

literature on summer gaps in three ways: 1) we document school year and summer gap dynamics using new nationally representative data from the Early Childhood Longitudinal Study, Kindergarten Class of 2010-2011 (ECLS-K:2011), which enables us to examine whether gap patterns in a more recent cohort are consistent with those from earlier studies; 2) the new data include more waves for school-year and summer analyses than earlier nationally-representative studies, allowing us to assess whether patterns are consistent as students age; finally, 3) we present a more complete picture of gap dynamics by operationalizing inequality as differences in learning rates as well as changes in relative status.

Background

Faucet Theory

Entwisle, Alexander, and Olson (2000) proposed the "faucet theory" to explain seasonal differences in learning by social class. The theory posits that during the school year, the "resource faucet" is on for all students; over the summer, however, the flow of resources slows for students from disadvantaged backgrounds but not for students from advantaged backgrounds. Relevant resources may be material or financial resources that enable access to high quality learning experiences, or may be human capital resources such as parental education, which can, for example, increase students' exposure to more varied and complex language (Borman, Benson, & Overman, 2005; Gershenson, 2013).

Past Research on Seasonal Inequality

SES gaps. Early studies in Atlanta by Heyns (1978) and by the Baltimore Beginning School Study (BSS; Entwisle & Alexander, 1992; Alexander et al., 2001) concluded that summer vacation had a detrimental effect (compared to the school year) on achievement gaps by SES. Data from the BSS showed that SES test score gaps widened as students progressed from elementary school to high school, and this widening occurred primarily over summer. Because these early studies took place in single cities, and with relatively homogeneous samples, the generalizability of their findings was unclear. Later analyses based on a nationally-representative sample of kindergarteners from the Early Childhood Longitudinal Study, Kindergarten Class of 1998-1999 (ECLS-K:99) supported the view that schools generally equalized student achievement, by slowing the rates of gap-widening (Downey et al., 2004). However, the ECLS-K:99 only permitted seasonal analyses from the fall of kindergarten through the spring of first grade.

Recent work by von Hippel and colleagues (2016) has called some of these findings into question, arguing that the BSS and ECLS-K:99 results were artifacts related to their testing procedures and the non-interval nature of their test scales. After re-analyzing the ECLS-K:99 data using the "theta" metric (which has greater theoretical claim to interval properties than the previously-used "number right true scores"), and analyzing national (though not nationally-representative) data from the Northwest Evaluation Association, the authors concluded that test score gaps by SES show little growth over elementary and

middle school, and these gaps "do not necessarily…grow fastest over the summer" (p. 41).

Racial/ethnic gaps. Findings on seasonal Black-White gaps have been mixed. While Heyns (1987) argued that "the entire racial gap in reading achievement is due to…'small differences' in summer learning" (p. 1158), analyses of the ECLS-K:99 suggested the opposite: that the Black-White gap widens over the school year but not the summer (controlling for SES; Downey et al., 2004; Condron, 2009). Less research exists on seasonal patterns in Hispanic-White and Asian-White gaps. Analyzing the ECLS-K:99, Downey et al. (2004) found no Hispanic-White differences in math or reading growth over the summer (controlling for SES); Asian students learned more math and reading over summer than White students. During the school year, White students sometimes learned more than Hispanic students, and results for school-year Asian-White learning gaps were mixed.

Operationalizing Inequality Dynamics

An important issue for seasonal gap analyses is that of how inequality is operationalized and how its dynamics are modelled (Quinn, 2015a). Many researchers conducting seasonal comparisons have used longitudinal growth models to document learning differences between groups by season (Downey et al., 2004; Alexander et al., 2001), while others have examined changes in standardized gaps, where test scores are standardized by the time-specific

standard deviation (Fryer & Levitt, 2004; von Hippel et al., 2016). Each approach provides a unique perspective on the question of whether achievement gaps narrow, widen, or remain unchanged.

Figure 1 presents a stylized illustration of this point. Imagine that students from group A and B took the same (vertically-equated) test at two time points, and each group's scores were normally distributed with different means and equal variance. The top and bottom panels show different ways in which the distributions might change from time 1 to time 2.

<Figure 1>

In the top panel, the absolute gap at time 1 is ten points ($\bar{A} - \bar{B}$ = -2 - 8 = -10), or .77 (pooled) *SD* units ($\frac{\bar{A}-\bar{B}}{SD_1} = \frac{-2-8}{13}$ = -.77). One way to represent gap dynamics is through the difference in groups' mean growth from time 1 to time 2, or the ΔT statistic (Ho, 2009). In the top panel, there is no difference in groups' mean growth; children in both groups gained 2 points, on average: $\Delta T = (\bar{A}_2 - \bar{A}_1) - (\bar{B}_2 - \bar{B}_1) = (0 - -2) - (10 - 8) = 0$. In an absolute sense, between-group inequality is unchanged. Nevertheless, because variance shrank over time, the two distributions overlap less at time 2 than time 1. Thus, in a relative sense, between-group inequality has grown. This change in relative position can be captured by the ΔG_{ES} statistic (ES="effect size"), in which the gap at each time point is expressed in time-specific standard deviation units: $\Delta G_{ES} = \frac{(\bar{A}_2 - \bar{B}_2)}{SD_2} -$

$\frac{(\bar{A}_1-\bar{B}_1)}{SD_1}$ (Ho, 2009). Here, the ΔG_{ES} statistic shows a gap-widening of 2.56 *SD*s ($\frac{0-10}{3}-\frac{-2-8}{13}--=-2.56\,SD$).

In the bottom panel, group B makes more growth than group A, on average ($\bar{B}_2-\bar{B}_1=10$; $\bar{A}_2-\bar{A}_1=2$), while variances remain unchanged. ΔT shows a mean growth difference of 8 points (i.e., absolute inequality increases), which we can express in time 1 *SD* for interpretability: $\Delta T_{SD_1}=\frac{-8}{10}=-.80\,SD$. Similarly, when expressed as ΔG_{ES}, the bottom panel shows a change in standardized gap of -.80 *SD* . Generally, ΔT_{SD_1} and ΔG_{ES} are equivalent if variance is constant, but can differ in magnitude or direction whenever variance changes. This is relevant for studies of seasonal gaps, because test score variance may shrink over the school year and expand over summer (Downey et al., 2004). Neither statistic is right nor wrong; rather, each reveals a different aspect of inequality dynamics. Unlike most studies on seasonal learning, we examine both aspects in order to get a more complete picture.

Summary and Research Question

Early studies on seasonal patterns of inequality generally found that SES test score gaps grew more over the summer than the school year. However, these studies often suffered from limited external validity or focused on a relatively short time period. Additionally, results for racial/ethnic gaps were mixed, and recent scholarship has called attention to the ways in which psychometric and

modeling issues can affect conclusions. In this study, we contribute to the literature by examining seasonal gap patterns using data from the most recent nationally-representative study, which follows students over a longer period of time than previous national studies. Importantly, unlike previous research, we offer a more complete picture of gap dynamics by examining changes in both absolute and relative gaps. Specifically, we ask, "At what monthly rates do math and reading test score gaps by race/ethnicity and SES change in absolute size over the school year and over the summer? At what monthly rates do these gaps change in relative size over the school year and summer?"

Methods

Data

ECLS-K:2011. The ECLS-K used a three-stage sampling design to obtain a nationally-representative sample of over 18,000 students attending kindergarten during the 2010-2011 school year (Tourangeau et al., 2012). Students were administered math and reading tests in the fall and spring of kindergarten (waves 1 and 2) and spring of grades 1 and 2 (waves 4 and 6). A subsample of students (approximately 30%) were randomly selected for additional testing in the fall of grades one and two (waves 3 and 5), allowing for the estimation of summer learning. Importantly, students were not tested on the first and last days of school, resulting in a "summer" period that includes school

days. We follow Downey et al.'s (2004) strategy for separating school year and summer trajectories (described below).

Assessments and Test Scales. At each testing, students were administered routing items to determine the difficulty level of their questions.[1] Students' achievement scores, θ_{it}, were estimated for each wave using a three-parameter logistic model. In theory, if model assumptions hold, the resulting scores represent a common vertical scale across test waves.

Samples. We use data only from students with non-missing predictors (see below) who attended schools following a nine-month calendar. Our models allow us to include outcome data from all students with at least one wave of test scores. See online Appendix B for comparisons of full and analytic samples; see Appendix C for results that include only students with complete test data (selected coefficients differ but overall pattern of results is similar).

Analytic Plan

We operationalize inequality dynamics in two ways: 1) as group mean differences in absolute learning – or equivalently, as changes in absolute gap size ($\Delta \mathrm{T}_{\mathrm{sd}_1}$); and 2) as group mean differences in change in relative status ($\Delta \mathrm{G}_{\mathrm{ES}}$). We estimate these statistics as monthly rates for each school year and summer ($\Delta \mathrm{T}_{\mathrm{sd}_1}^{(rate)}, \Delta G_{ES}^{(rate)}$). To account for the complex sampling design, all analyses incorporate weights and adjust standard errors.[2]

To estimate racial/ethnic differences in monthly growth rates by season ($\Delta T_{SD_1}^{(rate)}$) and monthly rates of standardized gap change ($\Delta G_{ES}^{(rate)}$), we fit versions of the following model:

(1)

$$Y_{it} = \alpha_i + \sum_r \beta_r \, RACE_i + \sum_p \eta_p \, MONTHS_{it}^{(Period\ P)} + \sum_k \tau_k \, (MONTHS_{it}^{(Period\ P)} \times RACE_i) + \sum_n \pi_n C_i + \sum_l \lambda_l \left(C_i \times MONTHS_{it}^{(Period\ P)} \right) + \epsilon_{it}$$

$$\epsilon_{it} \sim N\left(0,\ \sigma_y^2\right) \ \perp \ \alpha_i \sim N\left(\mu_\alpha,\ \sigma_\alpha^2\right)$$

where *i* indexes student, *t* indexes time, α_i represents a student-specific random intercept (to account for residual dependence within student), $\sum_r \beta_r \, RACE_i$ is a set of mutually exclusive racial/ethnic dummy variables (non-Hispanic Black, Hispanic, or Asian; non-Hispanic Whites are the reference group),[3] and $\sum_n \pi_n C_i$ includes the control variables: 1) indicator for first-time kindergartener, and 2) age at time of fall K test (results robust to exclusion of controls; see Appendix D). Importantly, $MONTHS_{it}^{(Period\ P)}$ represents a set of variables giving the number of months of period *P* (K school year, summer 1, Gr. 1, summer 2, Gr. 2) that student *i* had experienced when tested at wave *t* (see Appendix E).

For each outcome, we fit model 1 with two different metrics in order to estimate the rates of change in absolute (ΔT_{SD_1}) or relative (ΔG_{ES}) gaps. When

$Y_{it} = \frac{\theta_{it}}{\sqrt{r_1} \times SD_1}$ (i.e., student *i*'s time *t* test score divided by the reliability-adjusted time 1 *sd*), the interaction terms τ_k (interactions between race/ethnicity and the *MONTHS* variables) answer our RQ about monthly rates of absolute gap change over the school years and summers. That is, these terms represent the estimated mean differences in monthly learning rates between White students and the relevant racial/ethnic group, expressed in fall K *sd* units ($\Delta T_{SD_1}^{(rate)}$). When $Y_{it} = \frac{\theta_{it} - \overline{\theta_t}}{\sqrt{\overline{r_t}} \times SD_t}$, or the wave-standardized score (with *sd* adjusted by the wave-specific θ reliability), the interaction terms answer our RQ about monthly rates of relative gap change, or the changes in standardized gaps ($\Delta G_{ES}^{(rate)}$).

We estimate $\Delta T_{SD_1}^{(rate)}$ and $\Delta G_{ES}^{(rate)}$ between students from the 10th and 90th percentiles of the SES distribution using a model similar to model 1, except that we remove the race/ethnicity dummy variables (and associated interactions), and add a continuous SES index[4] along with interactions between SES and the $MONTHS_{it}^{(Period\ P)}$ variables. Using the model coefficients, we enter values for the 10th and 90th SES percentiles to estimate gap dynamics (see Appendix F).

For race/ethnicity and SES models, we obtain learning rates over each period for White students and students at the 90th percentile of SES, respectively (assuming mean values for controls).[5]

Previous researchers have compared gap changes over the school year to the gap changes over the summer. Under certain unverifiable assumptions, these differences-in-differences can be interpreted as the effect of schooling (compared to a no-school counterfactual) on test score gaps. We refrain from causal inferences, but note in our results when these differences-in-differences are consistent or inconsistent with the view of schools as equalizers.

Results

Descriptive Statistics

In Table 1, we present descriptive statistics by test wave for the full analytic sample, and by race/ethnicity, on reading and math scores and other key variables (Appendix H includes additional descriptive statistics). As noted earlier, the pattern of test score variance across waves is relevant to changes in standardized gaps. For the overall sample, variance in math and reading scores shrinks over K and grows over the post-K summer (though less for reading than math), consistent with the idea that students' learning experiences are more similar in school than non-school environments. However, the variances of math and reading scores shrink each subsequent wave (note the overall pattern sometimes differs by subgroup). As evident from inspecting sample sizes across waves, attrition for the analytic sample is relatively low (with maximum sample size discrepancy across full-sample test waves of 290 out of 11340; see Appendix I for sensitivity checks yielding nearly identical results to Table 3).

<Table 1>

Gaps at K entry and net gap changes from K-2. Following previous research on seasonal gap dynamics (Alexander et al., 2007; von Hippel et al., 2016), we begin in Table 2 by documenting the gaps at school entry and their net change (see Appendix J for detail). As demonstrated previously with these data (Quinn, 2015b; Reardon & Portilla, 2016), racial/ethnic and SES gaps exist in math and reading at kindergarten entry (columns 1 and 4 of Table 2, respectively). In both subjects, Asian students have the highest mean scores, followed by White students, Black students, and Hispanic students. Gaps between students from the 90th and 10th percentiles of SES are larger than any racial/ethnic gap (approximately 1.17 *sd*).

<Table 2>

By comparing $\Delta T_{SD_1}^{(K-2)}$(i.e., differences in growth from fall K to spring of 2nd; columns 2 and 5 of Table 2) to $\Delta G_{ES}^{(K-2)}$ (changes in standardized gaps from fall K to spring 2nd; columns 3 and 6 Table 2), we see that the way in which inequality is operationalized matters. In general, $\Delta G_{ES}^{(K-2)}$ presents a bleaker picture than does $\Delta T_{SD_1}^{(K-2)}$. For example, the Black-White reading gap shows no significant change from K to 2nd by $\Delta T_{SD_1}^{(K-2)}$, but $\Delta G_{ES}^{(K-2)}$ shows gap-widening of .22 *sd*. The Hispanic-White reading gap narrows by .13 *sd* with $\Delta T_{SD_1}^{(K-2)}$but is

constant for $\Delta G_{ES}^{(K-2)}$. A similar pattern is found for these gaps in math, and for SES gaps in math and reading.[6]

Seasonal Trends: $\Delta T_{SD_1}^{(rate)}$ and $\Delta G_{ES}^{(rate)}$ by School Year and Summer

Across gaps, subjects, and seasons, three general patterns emerge: 1) initially, gap trends generally show more equalizing over the school year than summer, but the equalizing pattern attenuates or reverses over time, 2) to the extent that equalizing occurs over the school year, it occurs more so for math than for reading, and 3) equalizing appears more for absolute, rather than relative, gaps. We organize the presentation of our results around these key findings, and provide numeric and visual summaries to communicate results. In Table 3, we present relevant coefficients from model 1 showing monthly rates of absolute gap change by season, along with expected growth rates for White students and high SES students (top panel), and monthly rates of relative gap change by season (bottom panel).

In Figure 2, we present one gap – the Hispanic-White gap – to serve as an illustration of our key findings, particularly the comparison of ΔT_{SD_1} and ΔG_{ES}. In this figure, the x-axes represent time and the y-axes represent gaps measured in a specified *sd*. Circular points represent gaps standardized by the fall K *sd*, so that the lines connecting circles track changes in absolute gaps (ΔT_{SD1}). Triangular points represent gaps expressed in wave-specific *sd* units, such that their

connecting lines represent changes in relative gap size (ΔG_{ES}). In Figure 3, we present ΔG_{ES} for all racial/ethnic and SES gaps. In both figures, positive slopes indicate gap-narrowing, while negative slopes indicate gap-widening. When the school year slope is either more positive or less negative than the slopes over adjacent summers, this demonstrates school-year equalizing.

<Table 3>

Initial school-year equalizing, then attenuation or reversal. The first key finding is that these results are consistent with a story in which schools tend to equalize initially, but this equalizing effect attenuates over time and in some cases reverses. For the Hispanic-White gaps depicted in Figure 2, this can be seen in two ways. First, the gap-change slopes are positive and steeper over K (indicating gap narrowing) than over grade 1 (when slopes are negative with mixed significance) or grade 2 (when slopes are mostly positive but shallower, and non-significant for reading). Importantly, comparisons of the school-year slopes and the slopes over adjacent summers generally show less contrast (in the direction of school-year equalizing) as students age. For example, when compared to the post-K summer math gap-widening, the steep positive slope over K is consistent with an equalizing effect of school. Over first grade, the math gap may widen, but not as quickly as over the post-K summer. In other words, equalizing still occurs over first grade, but not as notably as over K.

<Figure 2>

This pattern of initial school-year equalizing can also be seen in Table 3 for math and reading, where members of the relatively lower-achieving group in each pairwise comparison (e.g., Whites for Asian-White gaps, low SES students for high-low SES gaps) tend to learn more each month during kindergarten than do members of the higher-achieving group (i.e., the signs of the $\Delta T_{SD_1}^{(rate)}$ coefficients generally favor the lower-achieving group, the Black-White reading gap being the exception). Over the summer following K, absolute learning rates no longer favor the lower-achieving groups. School-year learning rate gaps over first grade – unlike K - are not more favorable for lower-achieving groups than the learning rate gaps over adjacent summers. Over first grade, the Black-White math gap widens in both absolute ($\Delta T_{SD_1}^{(rate)}$) and relative ($\Delta G_{ES}^{(rate)}$) terms, but remains constant over adjacent summers. For first grade reading, we see similar reversal for relative Black-White, Hispanic-White, and SES gaps. For the relative gaps in Figure 3, this result is most apparent for SES, which show steep positive slopes over K, followed by flat (reading) or significantly negative (math) slopes the following summer. This equalizing contrast reverses over grade 1 for reading (significant negative slope) and attenuates for math (nonsignificant slope).[7]

More school-year equalizing for math than reading. Second, to the extent that outcomes become more equal between groups over the school year than the summer, this pattern is more pronounced for math than reading. In

Figure 2, this comes across through the fact that school-year Hispanic-White slopes for math are always either more positive or less negative compared to the reading slopes over the same period, and the fact that school-year versus summer slope differences are starker for math than for reading (in the direction of school-year equalizing).

The general pattern is also evident in Table 3. For example, the absolute SES math gap narrows by .05 *sd* per month over K (column 1, last row of top panel), compared to summer-widening by .08 *sd* per month, a difference of .05--.08=.13 *sd* in favor of the school year. In contrast, the absolute SES reading gap narrows by .04 *sd* per month over K and widens by a statistically non-significant .02 per month the next summer, a school year advantage of only .06 *sd*. Moreover, ΔG_{ES} shows a widening Black-White reading gap over K, but no significant change in math. In Figure 3, this pattern comes across in that all math gaps except the Black-White gap narrow over K, while only SES and Asian-White reading gaps narrow. Additionally, gap-widening is more common over grade 1 for reading than math, and gap-narrowing more common over grade 2 for math than reading.

More school-year equalizing for absolute gaps. Finally, as foreshadowed by the net gap change results in Table 2, when we operationalize inequality dynamics as $\Delta G_{ES}^{(rate)}$, we generally find gap dynamics that paint a less optimistic picture of school-year equalizing, compared to when we operationalize

inequality dynamics as $\Delta T_{SD_1}^{(rate)}$. In Figure 2, this can be seen for the Hispanic-White gaps through the fact that during the school year, the slopes of the ΔG_{ES} lines tend to be less positive or more negative than those of ΔT_{SD1}, and sometimes ΔG_{ES} is more positive or less negative than ΔT_{SD1} over the summer.

In Table 3, this pattern appears with other gaps. The Black-White math gap narrows in absolute size over K, but does not change in relative size (same for K Hispanic-White reading gap). Over the post-K summer, the absolute SES math gap widens nearly twice as much as the relative gap. Over that summer, the absolute Black-White and Hispanic-White reading gaps remain constant while relative gaps narrow. Similarly, the Hispanic-White math gap widens in absolute size over the post-K summer but does not change in relative size. With these results, school-year versus summer comparisons show more school-year equalizing for absolute (ΔT_{SD1}), rather than relative (ΔG_{ES}) gaps.

<Figure 3>

Comparing across summers. We now take advantage of the additional summer included in the ECLS-K:2011 by more closely examining gap changes across the post-K and post-grade 1 summers.

All student groups always exhibit faster growth during school than during summer, and average decline in absolute scores over summer is relatively rare; groups' mean scores are mostly flat or rising (top panel of Table 3). Surprisingly, the only instance of absolute loss in these models appears for high SES students,

in reading during the post-grade 1 summer (absolute loss does not appear without adjusting for test date; see Appendix G).

More often than not, summer learning rates are similar across social groups. In math, most groups make absolute gains over the post-K summer, except that Hispanic students and low SES students show flat trajectories (p=.38 for null of no change), resulting in absolute gap-widening for these groups. The next summer, we find no absolute math gap-widening, as all groups exhibit flat trajectories. For reading, mean learning rates are mostly flat over the post-K summer, except that Asian students make progress. Over the post-grade 1 summer, all racial/ethnic groups show stagnating reading scores. In a departure from previous literature, low SES students show greater reading gains over the post-grade 1 summer than do high SES students (who, as noted, experience loss on average).

Due to test score variance changing over summer, absolute and relative gap dynamics often differ from one another, particularly over the post-K summer. In math, the increasing variance over this summer cancels out the Hispanic-White learning rate difference (which favors White students), resulting in non-significant Hispanic-White gap change (right panel, Figure 2). Similarly, the relative SES gap widens at nearly half the rate of the absolute SES gap. Over the post-grade 1 summer, both absolute and relative math gaps are mostly unchanged, except that the relative Black-White gap narrows while the absolute gap remains constant

(right panel, Figure 3). Although the absolute Black-White and Hispanic-White reading gaps are stagnant over the post-k summer, the growing variance means that these gaps narrow in relative terms (left panel, Figure 3). The next summer, the shrinking reading variance cancels out the growth advantage experienced by low SES students, resulting in no relative SES gap change.

Discussion

In this study, we used the most recent nationally-representative data available for comparing inequality dynamics across seasons, and document a longer time period than was possible with earlier nationally-representative studies. We also extend previous research by examining inequality in both absolute and relative terms. Our results are partially consistent with the idea of schools as equalizers. We find initial school-year equalizing, whereby lower-achieving groups experience steeper learning trajectories than higher-achieving groups (i.e., ΔT_{SD_1} show gap-narrowing over K); however, this pattern is not consistently maintained over time, and in some cases reverses. To the extent that school-year equalizing does occur, it is more pronounced for math than for reading. Finally, because test score variance changes over time, our picture of inequality dynamics depends on how we operationalize gaps. When examining changes in absolute (rather than relative) inequality, school-year equalizing is more apparent and the pattern of reversal, in which later years show inequality growing more during the school year than during the summer, is less common. As in previous research

(Downey et al., 2004), Black-White gaps stand out because their dynamics are more consistent with schools exacerbating, rather than alleviating, inequality.

Interpreting Patterns.

If schools are more successful at helping lower-achieving groups catch up to higher-achieving groups over kindergarten than over subsequent years, the reason may relate to curriculum. Students who enter kindergarten with weaker basic skills will benefit more from the typical kindergarten curriculum than students who enter kindergarten with mastery of basic skills (Engel, Claessens, & Finch, 2013). In later grades, when curricular content begins to move beyond the basics, the potential to equalize through simple curricular exposure may be lessened.

The contrast between school-year and summer gap dynamics may be stronger in math than reading because when out of school, students receive more exposure to literacy-enriching inputs than math-enriching inputs (Burkam et al., 2004; Cooper et al., 1996; Murnane, 1975). While it may be that most students access literacy-related experiences over the summer that maintain their skill levels, perhaps only advantaged students experience adequate exposure to math-enhancing inputs over the summer following kindergarten.

Our results also demonstrate the value of examining ΔT and ΔG_{ES} together, rather than choosing just one, as in previous seasonal research. Had we only estimated ΔT, we would have generally gleaned a more positive (or less

negative) impression of how inequality changes in early childhood. This is seen most starkly when comparing net gap change from K to 2nd (Table 2) and Black-White and SES gap changes over summer. Had we only estimated ΔG_{ES}, we would have concluded that Hispanic-White inequality in math did not change over the post-K summer, without realizing that the average White student gained in math over this summer while Hispanic students' trajectories were flat. Additionally, from ΔG_{ES} alone, we would have concluded that Black-White inequality in math decreased over the post-grade 1 summer, without realizing that Black and White students alike experienced flat math trajectories those months. Such different "facts" about inequality dynamics are likely to be seen by policymakers and practitioners as justification for different policy choices. By considering ΔT and ΔG_{ES} together, we get a more complete story of inequality dynamics.

Comparing across Cohorts

The past analyses of the ECLS-K:99 that are most comparable to any we conducted are von Hippel and colleagues' (2016) analyses using wave-standardized theta scores (analogous to our ΔG_{ES} results). Generally, their results share some similarities with our results using the ECLS-K:2011. Both studies showed school-year equalizing in early grades for Hispanic-White gaps and low-high SES gaps, but not for Black-White gaps. However, the authors report mean gap changes over K and grade 1 (as opposed to separately by grade level), so it is

unclear whether the equalizing attenuates. The authors also found that lower-income students fall further behind their higher-income peers in math and reading over the post-K summer; we find this only for math (though von Hippel and colleagues use meal subsidy status to measure SES). Finally, we find narrowing of the Black-White reading gap over the post-K summer while they do not.

Future Research

Our results highlight several important areas for future research. Whether the attenuation of school-year equalizing indicates that schools are better at equalizing learning on basic skills than on more complex material is unclear. Certain racial trends also deserve more attention. For instance, an understanding of why Black-White gaps are maintained during the school year when other gaps narrow is particularly relevant for school interventions. Furthermore, while these data have the advantage of showing what happens on average in the United States, patterns likely vary across locales. Research into what variation exists at the school-, district-, or state-levels, and what predicts the variation, may help shed light onto the potential mechanisms behind these patterns. Lastly, the finding that high SES students experience declines in reading over the post-grade 1 summer while low SES students do not is an anomaly in the literature that merits investigation.

Conclusion

This study presents descriptive findings on the seasonal dynamics of inequality in math and reading over the first three years of schooling. While these results draw attention to potential opportunities for interventions aimed at ending inequities by race/ethnicity and SES, these results alone cannot answer questions about which educational policies or practices should be pursued. Such questions require additional evidence comparing the relative effectiveness and costs of various school-year and summer solutions.

As an illustration, policymakers interested in summer interventions may notice the following implication of our results: if the mean reading growth rate of Black students over each summer vacation equaled the Black mean reading growth rate from the previous school year (all else unchanged), the Black-White reading gap in the spring of second grade would favor Black students by approximately .31 fall K *sd* (as opposed to favoring White students by .40 *sd*). This does not necessarily imply that summer interventions are the answer, however, as the decision to pursue summer-based solutions requires an understanding of the practicality, relative cost-effectiveness, value trade-offs, and potential unintended consequences of specific interventions. For example, traditional summer school programs often have difficulty attracting high quality teachers (Denton, 2002) and appealing to students and families (McLaughlin & Pitcock, 2009). Overcoming such challenges requires resources, and these resources may add more value if applied during the school year, when teachers

and students are already assembled and when there is potential for these additional resources to positively interact with the resources already being directed toward student learning. On the other hand, innovative summer solutions may have a role to play; for example, some evidence suggests that home-based summer reading programs may be a cost-effective alternative to traditional summer school (Kim, Guryan, White, Quinn, Capotosto, & Kingston, 2016; Kim & Quinn, 2013).

The optimal solution that maximizes gap closure while balancing considerations of other equity issues – such as potential inequality in summer vacation privileges – may be some combination of school-year efforts and traditional or non-traditional summer interventions. While crafting the optimal solution is beyond the scope of this article, our findings provide descriptive facts that are useful to the separate goal of understanding how policy and practice can maximize the equalizing potential of schools.

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Notes

[1] Translated math assessments and brief Spanish basic reading tests were administered to Spanish-speaking students who did not pass an English screener. Some of the Hispanic-White gap trends differ in magnitude and significance (but never direction) when models exclude students who ever took a translated assessment (See online Appendix A).

[2]We fit models in Stata 14 applying weight W1C0 with the command suites *meglm* and *svy* (which adjusts standard errors to account for the dependence of residuals within primary sampling units). Results are robust to use of different, or no, sampling weights.

[3]Due to small sample sizes for Native Hawaiian/Pacific Islander, American Indian/Alaska Native, and multi-racial, we include these groups in our models as an "other race" category but do not report their gap trends.

[4] We use the NCES-created SES variable, which is a composite of family income, parental education, and occupational prestige; see Tourangeau et al. (2012).

[5] One assumption of model 1 is that growth rates are linear within each time period. For each test wave, the resemblance of the linear trend of test scores over time to local polynomial smoothing and LOWESS curves supported the linearity assumption, consistent with findings from Fitzpatrick, Grissmer, & Hastedt (2011) using the ECLS-K:1999. See Appendix G for piecewise longitudinal models that do not adjust for test date, relaxing the linear growth assumption

(while changing interpretation of coefficients). Model 1 also assumes that test score variance is the same at each time point and that test score covariances are constant across time. Alternative models that allow for unrestricted covariance matrices support the same conclusions as those reported here.

[6] See Appendix K for sensitivity analyses using *V* (Ho, 2009), which relax the interval scale assumption (pattern of results is similar).

[7] Analyzing the same data set, Quinn (2015b) finds significant widening of the Black-White math gap by ΔG_{ES} over K (with a different modeling strategy and fewer sample restrictions compared to the present analyses). Reardon and Portilla (2016) find no significant change in the Black-White math or reading gaps and no significant change in the Hispanic-White reading gap over K, with gap-change magnitudes that are similar to ours (our estimates differ from Reardon & Portilla's [2016] due to different sample restrictions, modeling strategies, and accounting for correlation of scores within student).

Table 1.
Weighted Descriptive Statistics by Race/Ethnicity across Waves.

		Overall			Black			Hispanic			Asian			White		
	Wave	*M*	*sd*	*n*	*M*	*sd*	*n*	*M*	*sd*	*n*	*M*	*sd*	*n*	*M*	*sd*	*n*
Math θ/sd_1	Fall K	-0.524	1.028	11280	-0.871	0.974	1330	-1.004	1.086	2800	-0.082	0.955	810	-0.262	0.905	5710
	Spr. K	0.508	0.863	11300	0.137	0.901	1330	0.2	0.874	2810	0.77	0.806	830	0.711	0.783	5710
	Fall 1	1.002	0.921	3750	0.653	0.824	360	0.72	0.821	1350	1.322	0.886	290	1.286	0.921	1520
	Spr. 1	1.86	0.949	11120	1.379	0.827	1300	1.481	0.88	2730	2.159	0.866	840	2.116	0.904	5640
	Fall 2	2.09	0.925	3630	1.657	0.861	340	1.775	0.878	1310	2.521	0.792	280	2.408	0.855	1480
	Spr. 2	2.746	0.901	11040	2.202	0.885	1290	2.432	0.875	2710	3.146	0.776	830	2.976	0.819	5610
Read θ/sd_1	Fall K	-0.631	1.029	11340	-0.797	0.973	1340	-1.039	1.01	2790	-0.214	1.183	850	-0.439	0.97	5730
	Spr. K	0.568	0.933	11330	0.35	0.956	1330	0.239	0.994	2810	0.854	1.02	850	0.747	0.832	5710
	Fall 1	1.029	0.947	3740	0.861	0.931	360	0.791	0.9	1330	1.522	0.984	290	1.223	0.923	1520
	Spr. 1	1.952	0.914	11120	1.702	0.879	1300	1.619	0.918	2730	2.252	0.83	840	2.133	0.863	5640
	Fall 2	2.202	0.812	3630	1.992	0.757	340	1.955	0.765	1310	2.528	0.651	280	2.427	0.8	1470
	Spr. 2	2.675	0.769	11050	2.417	0.725	1290	2.407	0.776	2710	2.908	0.679	830	2.835	0.728	5610
SES 1st	Fall K	-0.035	0.809	10530	-0.369	0.714	1200	-0.525	0.717	2540	0.342	0.892	770	0.224	0.729	5430
Time K	Fall K	0.949	0.22	11400	0.925	0.263	1340	0.943	0.232	2830	0.953	0.211	860	0.955	0.208	5740
Age (mo.) Fall K	Fall K	67.585	4.464	11400	67.328	4.694	1340	66.99	4.255	2830	66.249	4.318	860	68.034	4.488	5740

Note. Sample weight W1C0 applied. Sample sizes rounded to the nearest 10, as required by NCES. Sample sizes by race do not sum to overall because "other race" subgroup is included in the overall descriptive statistics (and models below). Reliability-adjusted *sd* used.

Table 2.

Math and Reading Gaps by Race/ethnicity and SES at Kindergarten Entry, and Net Differences in Growth and Changes in Standardized Gaps from Fall of K to Spring of Grade 2

	Math			Reading		
	(1)	(2)	(3)	(4)	(5)	(6)
	Fall K Gap	ΔT_{SD_1} Total, Fall K to Spr. Gr.2	ΔG_{ES} Total, Fall K to Spr. Gr.2	Fall K Gap	ΔT_{SD_1} Total, Fall K to Spr. Gr.2	ΔG_{ES} Total, Fall K to Spr. Gr.2
Black-White	-.568***	-.179***	-.277***	-.318***	-.082	-.223***
	(.051)	(.035)	(.038)	(.056)	(.051)	(.057)
Hispanic-White	-.661***	.147***	.081~	-.54***	.13**	-.01
	(.041)	(.042)	(.044)	(.043)	(.045)	(.05)
Asian-White	.254***	-.034	-.002	.28***	-.189***	-.159***
	(.052)	(.035)	(.036)	(.062)	(.046)	(.045)
10th - 90th SES	-1.177***	.244***	.123***	-1.173***	.342***	.059~
	(.034)	(.035)	(.036)	(.036)	(.032)	(.034)

Note. Sampling weight W1C0 applied. Standard errors that account for the complex sampling design are in parentheses. SES=socioeconomic status (continuous composite of parental income, education, and occupational prestige). Racial/ethnic gaps and SES gaps estimated in separate models (other race – White gaps estimated but not shown). All standardizations adjust for test reliability. Estimates derived from longitudinal model with indicator variable specification for time and random intercepts for students, incorporating all available test data and adjusting for time-varying effects of student age at time of fall K assessment and whether student was a first-time kindergartener; see online Appendix J for models. Models use same analytic sample as results in Table 3; see Table 1 for information on the analytic sample.

*~p<.10, *p<.05, **p<.01, ***p<.001.*

Table 3.

Monthly Learning Rates (White Students, High SES Students) and Differences in Monthly Learning Rates by Race/ethnicity and SES, over each School Year and Summer in Fall K sd Units (Top Panel); Monthly Rates of Changes in Standardized Gaps over each School Year and Summer (Bottom Panel).

	Math					Reading				
	K	Sum. 1	Gr. 1	Sum. 2	Gr. 2	K	Sum. 1	Gr. 1	Sum. 2	Gr. 2
					$\Delta T_{SD_1}^{(rate)}$					
White Students	.162***	.069***	.124***	0	.087***	.199***	0	.137***	-.006	.067***
	(.003)	(.012)	(.004)	(.009)	(.003)	(.003)	(.016)	(.005)	(.008)	(.002)
Black-White	.009*	-.024	-.017**	.015	-.007	-.007~	.019	-.01~	.023	-.005
	(.004)	(.018)	(.005)	(.013)	(.004)	(.004)	(.018)	(.006)	(.014)	(.004)
Hispanic-White	.037***	-.065**	-.004	-.018	.014*	.012**	.003	-.005	.012	.004
	(.005)	(.02)	(.004)	(.017)	(.006)	(.005)	(.019)	(.005)	(.014)	(.004)
Asian-White	-.015***	-.017	.007	.017	.004	-.013*	.055**	-.017**	.004	-.009
	(.004)	(.023)	(.008)	(.015)	(.005)	(.006)	(.02)	(.006)	(.02)	(.006)
90th Pct. SES	.142***	.09***	.123***	-.001	.084***	.178***	.02	.134***	-.02*	.065***
	(.002)	(.012)	(.003)	(.009)	(.003)	(.002)	(.014)	(.005)	(.009)	(.003)
10th - 90th SES	.053***	-.08***	-.002	-.007	.012**	.039***	-.019	-.002	.04***	.003
	(.004)	(.014)	(.004)	(.012)	(.004)	(.005)	(.016)	(.005)	(.011)	(.003)
					$\Delta G_{ES}^{(rate)}$					
Black-White	-.008	.018	-.02***	.032*	-.014**	-.014**	.059**	-.02***	.029~	-.015**
	(.005)	(.023)	(.007)	(.015)	(.005)	(.005)	(.021)	(.006)	(.016)	(.005)
Hispanic-White	.024***	-.026	-.008~	-.014	.012*	.005	.045*	-.017**	.004	-.001
	(.005)	(.019)	(.005)	(.02)	(.006)	(.005)	(.019)	(.005)	(.017)	(.005)
Asian-White	-.015**	0	.002	.034~	.003	-.016*	.089***	-.03***	.028	-.013~
	(.005)	(.025)	(.008)	(.019)	(.006)	(.006)	(.018)	(.006)	(.023)	(.008)
10th - 90th SES	.028***	-.044*	-.001	-.012	.009~	.026***	.007	-.013**	.01	-.007~
	(.005)	(.017)	(.005)	(.014)	(.005)	(.006)	(.018)	(.005)	(.012)	(.004)

Note. Sampling weight W1C0 applied. Standard errors that account for the complex sampling design are in parentheses. SES=socioeconomic status (continuous composite of parental income, education, and occupational prestige). Racial/ethnic gaps and SES gaps estimated in separate models (other race – White gaps estimated but not shown). All standardizations adjust for test reliability. Estimates derived from longitudinal model with random intercepts for students,

incorporating all available test data and adjusting for test date, time-varying effects of student age at time of fall K assessment and whether student was a first-time kindergartener. See Table 1 for information on the analytic sample.
*~p<.10, *p<.05, **p<.01, ***p<.001.*

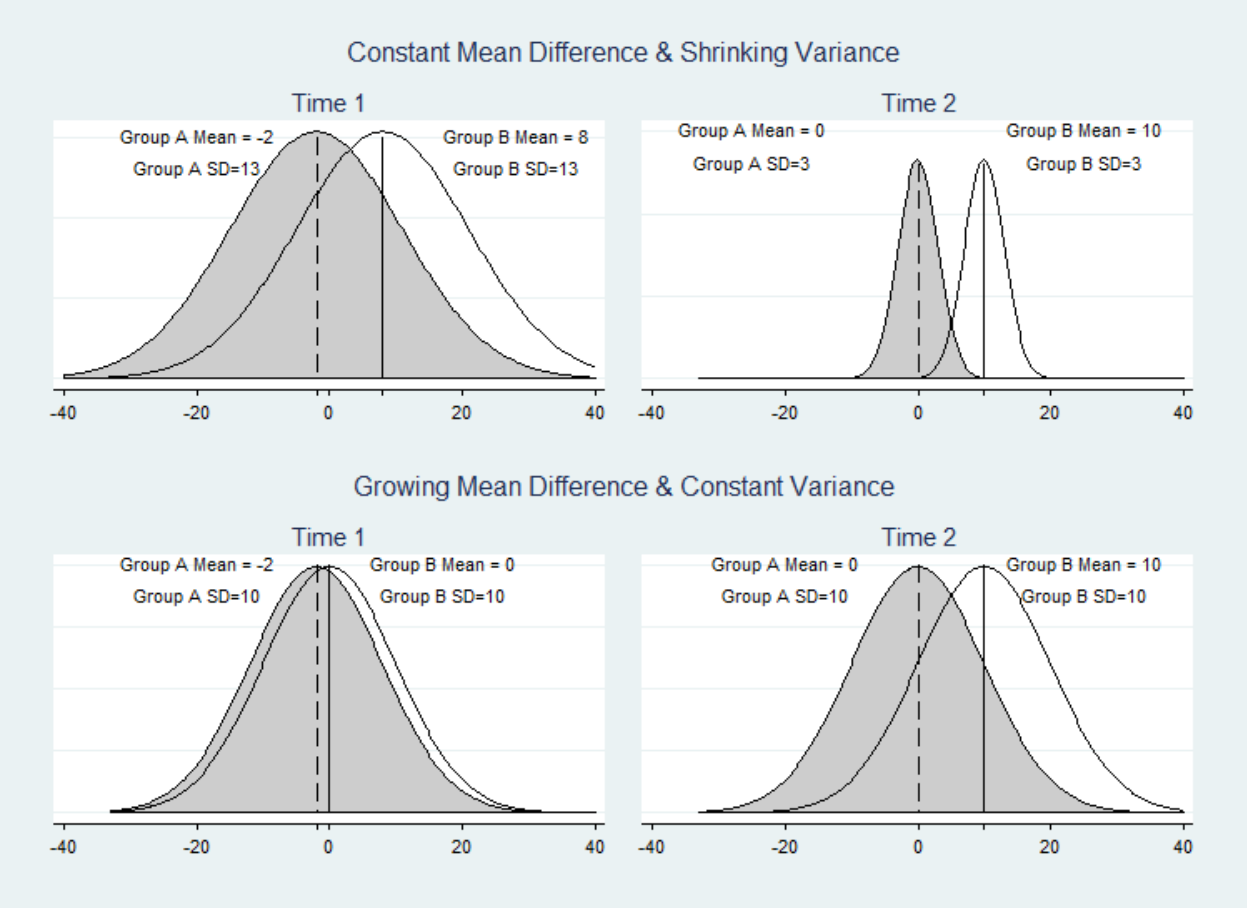

Figure 1. Stylized illustration distinguishing between changes in absolute and relative inequality. Top panel shows constant absolute inequality but increasing relative inequality (y-axes scaled differently to fit curves); bottom panel shows increasing absolute and relative inequality.

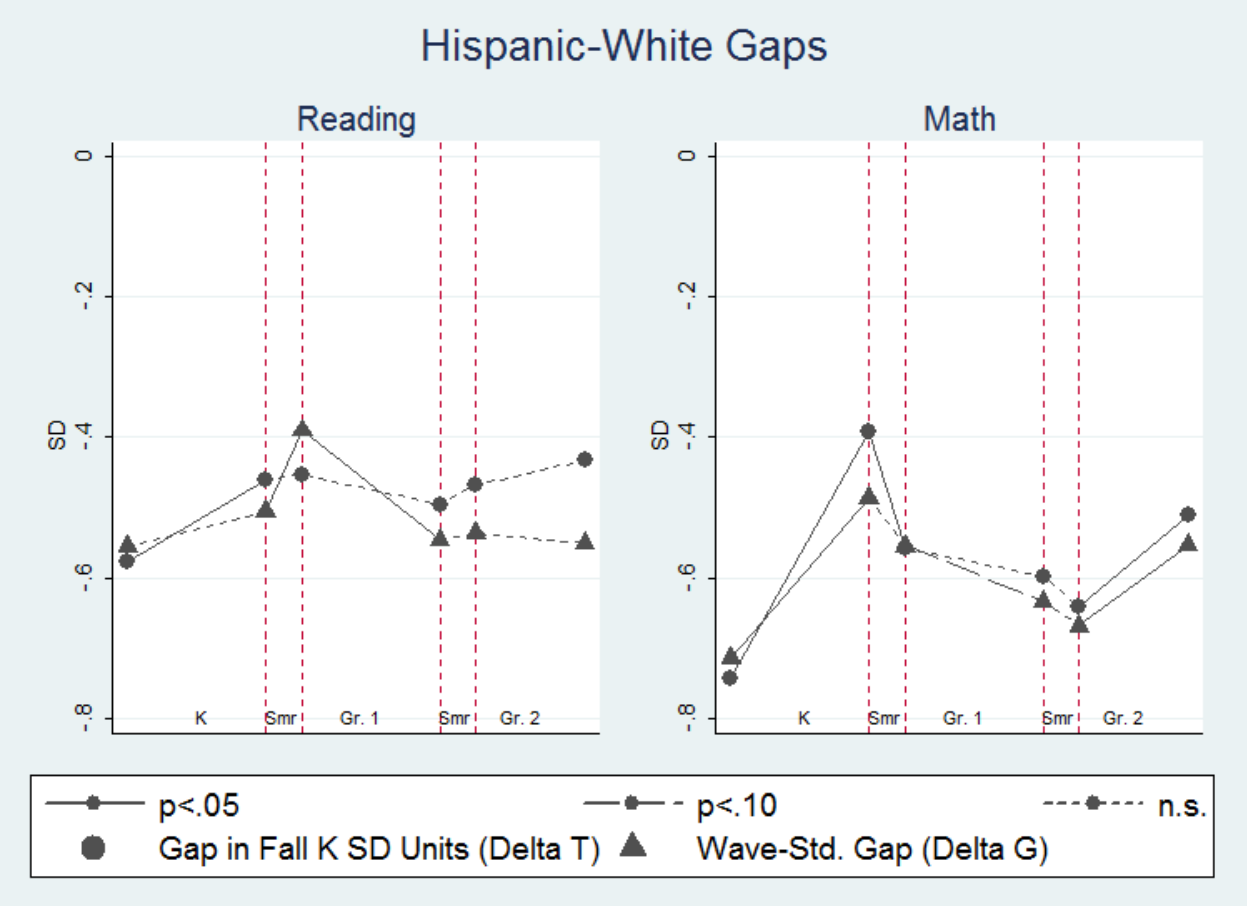

Figure 2. Changes in absolute and relative Hispanic-White reading and math gaps by season. Slopes for lines are monthly rates of gap changes shown in Table 3; points marking the beginning and end of each school year or summer are projected to the beginning/end of school year/summer assuming 9.5-month school year and 2.5-month summer.

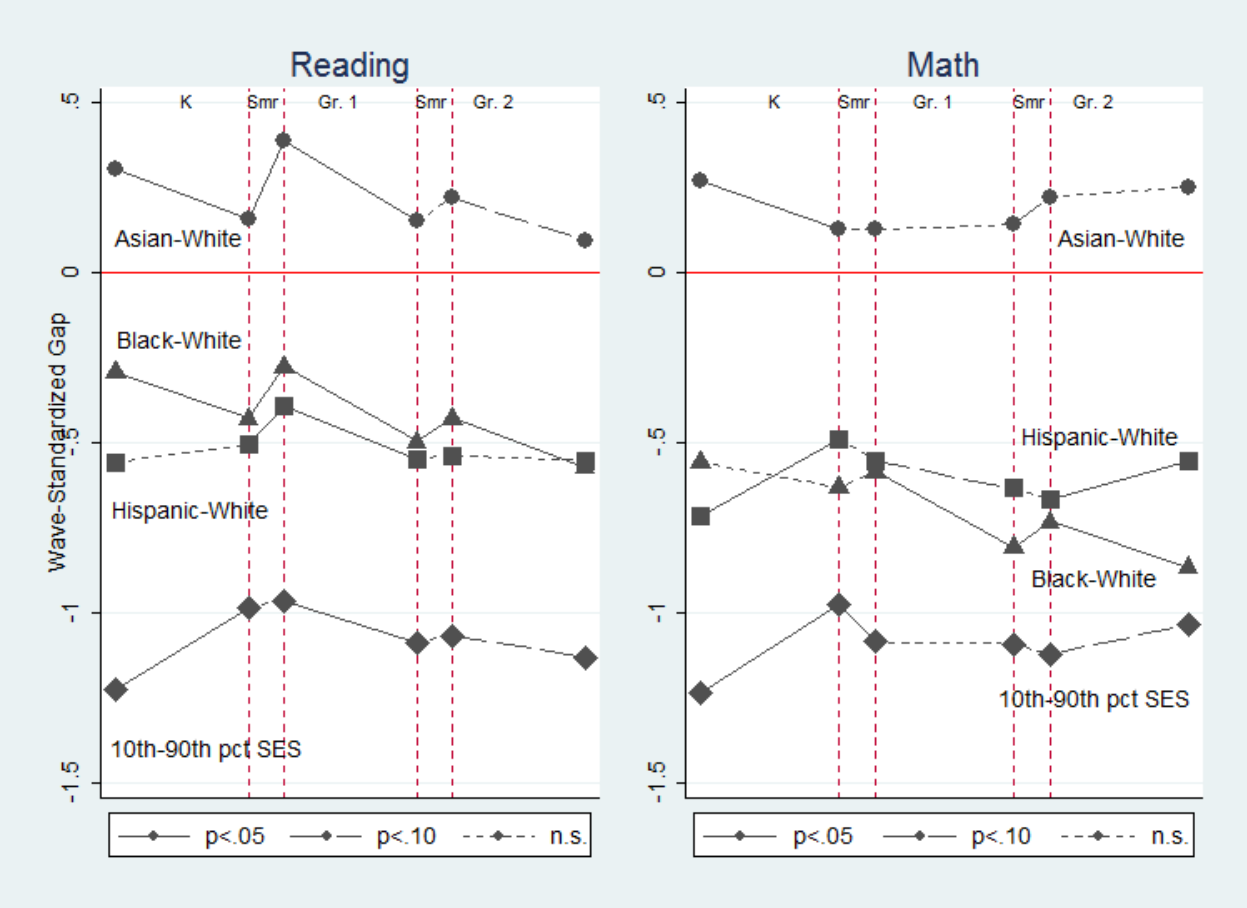

Figure 3. Changes in relative gaps (ΔG_{ES}) for reading and math by season. Slopes of lines are monthly rates of standardized gap changes shown in Table 3; points marking the beginning and end of each school year or summer are projected to the beginning/end of school year/summer assuming 9.5-month school year and 2.5-month summer.

Online Appendix A. Models using Students who Took English Language Assessments at each Wave.

Table A1.
Models Estimating Monthly Rates of Learning (Reference Group Students) and Differences in Monthly Learning Rates by Race/ethnicity and SES, over each School Year and Summer in Fall K SD Units (Top Panel); Models Estimating Monthly Rates of Changes in Standardized Gaps over each School Year and Summer (Bottom Panel), Only Students who took English language assessments each wave.

	Math					Reading				
	K	Sum. 1	Gr. 1	Sum. 2	Gr. 2	K	Sum. 1	Gr. 1	Sum. 2	Gr. 2
	ΔT_{SD_1}									
White Students	.162***	.069***	.124***	0	.087***	.199***	0	.137***	-.006	.067***
	(.003)	(.012)	(.004)	(.009)	(.003)	(.003)	(.016)	(.005)	(.008)	(.002)
Black-White	.009*	-.025	-.017**	.014	-.007	-.008~	.017	-.009	.021	-.005
	(.004)	(.018)	(.005)	(.013)	(.004)	(.004)	(.018)	(.006)	(.014)	(.004)
Hispanic-White	.031***	-.056**	-.006	-.014	.013*	.017***	-.018	-.004	.004	.004
	(.005)	(.019)	(.004)	(.018)	(.005)	(.004)	(.018)	(.005)	(.015)	(.004)
Asian-White	-.014**	-.015	.006	.018	.004	-.014*	.054**	-.018**	.007	-.011~
	(.005)	(.023)	(.007)	(.015)	(.005)	(.006)	(.02)	(.006)	(.02)	(.006)
90th Pct. SES	.143***	.088***	.123***	-.003	.085***	.177***	.022	.134***	-.02*	.065***
	(.002)	(.012)	(.003)	(.009)	(.003)	(.002)	(.014)	(.005)	(.009)	(.003)
10th - 90th SES	.046***	-.07***	-.004	0	.01*	.042***	-.034*	-.002	.035**	.003
	(.004)	(.013)	(.004)	(.011)	(.004)	(.004)	(.014)	(.005)	(.011)	(.003)
	ΔG_{ES}									
Black-White	-.008	.017	-.024***	.031*	-.014**	-.015**	.057**	-.023***	.027~	-.015**
	(.005)	(.023)	(.007)	(.015)	(.005)	(.005)	(.021)	(.006)	(.015)	(.005)
Hispanic-White	.019***	-.018	-.01*	-.008	.011~	.011*	.022	-.016**	-.001	-.001
	(.005)	(.019)	(.005)	(.02)	(.006)	(.004)	(.018)	(.005)	(.017)	(.005)
Asian-White	-.014**	.002	0	.035~	.003	-.017*	.087***	-.025***	.03	-.014~
	(.005)	(.025)	(.008)	(.019)	(.006)	(.007)	(.017)	(.005)	(.023)	(.008)
10th - 90th SES	.022***	-.036*	-.002	-.005	.007	.03***	-.012	-.012*	.007	-.006~
	(.004)	(.017)	(.005)	(.012)	(.004)	(.004)	(.015)	(.005)	(.011)	(.004)

Note. SES=socioeconomic status (continuous composite). Racial/ethnic gaps and SES gaps estimated in separate models (other race – White gaps estimated but not shown). Standard errors that account for the complex sampling design are in parentheses. All standardizations adjust for test reliability. Estimates derived from longitudinal model with random intercepts for students, adjusting for time-varying effects of student age at time of fall K assessment and whether student was a first-time kindergartener.
*~p<.10, *p<.05, **p<.01, ***p<.001.*

Online Appendix B. Comparisons of Analytic Samples to Students Dropped from Analytic Samples, for Race/ethnicity Models and SES Models

Table B1.

Comparison of Key Variables for Analytic Sample and Students Dropped from Analytic Sample Due to Missingness on ≥ 1 Variable (Race/ethnicity Models).

	Students Dropped from Sample			Analytic Sample				
	Mean	SD	N	Mean	SD	N	Difference	*p*
Black	0.157	0.364	6730	0.117	0.322	11400	0.04	<.001
Hispanic	0.261	0.439	6730	0.248	0.432	11400	0.013	0.374
Asian	0.103	0.304	6730	0.075	0.263	11400	0.028	0.003
Other Race	0.069	0.254	6730	0.057	0.231	11400	0.013	0.011
White	0.41	0.492	6730	0.503	0.5	11400	-0.093	<.001
Math θ Wave 1	-0.616	0.936	4320	-0.448	0.923	11280	-0.168	<.001
Math θ Wave 2	0.398	0.776	5840	0.473	0.765	11310	-0.074	<.001
Math θ Wave 3	0.823	0.868	1400	0.914	0.821	3830	-0.091	0.041
Math θ Wave 4	1.57	0.864	3770	1.672	0.847	11340	-0.103	<.001
Math θ Wave 5	1.798	0.938	1000	1.881	0.828	3740	-0.082	0.106
Math θ Wave 6	2.374	0.88	2480	2.471	0.806	11360	-0.096	0.002
Read. θ Wave 1	-0.634	0.843	4340	-0.507	0.852	11340	-0.127	<.001
Read. θ Wave 2	0.393	0.808	5850	0.475	0.773	11340	-0.082	<.001
Read. θ Wave 3	0.793	0.835	1390	0.867	0.78	3810	-0.074	0.095
Read. θ Wave 4	1.521	0.785	3770	1.611	0.751	11350	-0.09	<.001
Read. θ Wave 5	1.713	0.699	1000	1.82	0.665	3730	-0.107	0.007
Read. θ Wave 6	2.091	0.68	2490	2.211	0.631	11360	-0.12	<.001
SES	-0.124	0.809	5440	-0.015	0.815	10540	-0.109	<.001
1st Time K	0.938	0.241	4480	0.951	0.216	11400	-0.013	0.009
Age in Months. At Wave 1	67.249	4.639	4380	67.531	4.41	11400	-0.282	0.021

Note. p-value is for test of null hypothesis of no mean difference between students in analytic sample and students dropped from analytic sample. Sample sizes rounded to nearest 10, as required by NCES.

Table B2.

Coefficients and p-values for Interaction Terms between Race/ethnicity Indicators and Indicator for Whether Student is in Analytic Sample, Predicting Key Variables (Race/ethnicity Models; non-Hispanic White is Reference Group).

	Black		Hispanic		Asian		Other Race	
	Interaction *b*	Interaction *p*	Interaction *b*	Interaction *p*	Interaction *b*	Interaction *p*	Interaction *b*	Interaction *p*
Math θ Wave 1	0.204	<.001	0.078	0.171	0.152	0.016	-0.178	0.019
Math θ Wave 2	0.132	0.001	0.08	0.03	0.161	0.001	-0.032	0.548
Math θ Wave 3	0.012	0.904	-0.031	0.688	0.145	0.256	-0.089	0.513
Math θ Wave 4	0.087	0.079	0.095	0.027	0.068	0.255	-0.116	0.125
Math θ Wave 5	0.14	0.204	0.009	0.914	0.035	0.821	-0.055	0.742
Math θ Wave 6	0.081	0.245	0.075	0.119	0.115	0.093	-0.113	0.197
Read. θ Wave 1	0.078	0.125	0.076	0.11	0.118	0.17	-0.116	0.097
Read. θ Wave 2	0.037	0.385	0.031	0.421	0.08	0.243	-0.02	0.743
Read. θ Wave 3	-0.118	0.241	-0.15	0.05	-0.003	0.978	-0.116	0.397
Read. θ Wave 4	-0.015	0.762	<.001	0.996	-0.036	0.507	-0.118	0.082
Read. θ Wave 5	0.017	0.851	-0.022	0.764	-0.023	0.817	-0.05	0.694
Read. θ Wave 6	-0.037	0.529	0.004	0.924	-0.001	0.979	-0.081	0.269
SES	0.12	0.023	0.131	0.002	0.132	0.13	-0.059	0.31
1st Time K	-0.02	0.267	0.017	0.098	0.031	0.051	-0.044	0.012
Age in Months. At Wave 1	0.668	0.012	0.077	0.734	-0.198	0.586	0.461	0.166

Table B3.

Comparison of Key Variables for Analytic Sample and Students Dropped from Analytic Sample Due to Missingness on ≥ 1 Variable (SES Models).

	Students Dropped from Sample			Analytic Sample				
	Mean	SD	N	Mean	SD	N	Difference	*p*
Black	0.158	0.364	7600	0.114	0.318	10540	0.044	<.001
Hispanic	0.269	0.443	7600	0.241	0.428	10540	0.027	0.033
Asian	0.103	0.304	7600	0.072	0.259	10540	0.031	<.001
Other Race	0.066	0.249	7600	0.058	0.233	10540	0.009	0.067
White	0.404	0.491	7600	0.515	0.5	10540	-0.11	<.001
Math θ Wave 1	-0.639	0.928	5170	-0.423	0.922	10440	-0.216	<.001
Math θ Wave 2	0.384	0.769	6690	0.488	0.767	10460	-0.103	<.001
Math θ Wave 3	0.803	0.843	1720	0.932	0.827	3510	-0.13	0.001
Math θ Wave 4	1.543	0.852	4630	1.693	0.848	10480	-0.149	<.001
Math θ Wave 5	1.77	0.907	1320	1.899	0.829	3420	-0.129	0.003
Math θ Wave 6	2.346	0.856	3340	2.487	0.806	10490	-0.141	<.001
Read. θ Wave 1	-0.661	0.831	5200	-0.483	0.856	10480	-0.177	<.001
Read. θ Wave 2	0.378	0.799	6710	0.491	0.775	10490	-0.113	<.001
Read. θ Wave 3	0.763	0.813	1710	0.889	0.784	3490	-0.126	0.002
Read. θ Wave 4	1.503	0.771	4630	1.626	0.753	10490	-0.123	<.001
Read. θ Wave 5	1.697	0.681	1320	1.836	0.667	3410	-0.139	<.001
Read. θ Wave 6	2.08	0.656	3350	2.224	0.633	10500	-0.145	<.001
SES	-0.124	0.809	5440	-0.015	0.815	10540	-0.109	<.001
1st Time K	0.941	0.235	5350	0.951	0.217	10540	-0.009	0.055
Age in Months. At Wave 1	67.241	4.615	5250	67.558	4.403	10540	-0.317	0.004

Note. p-value is for test of null hypothesis of no mean difference between students in analytic sample and students dropped from analytic sample. Sample sizes rounded to nearest 10, as required by NCES.

Table B4.
Coefficients and p-values for Interaction Terms between SES and Indicator for Whether Student is in Analytic Sample, Predicting Key Variables (SES Models).

	SES	
	Interaction *b*	Interaction *p*
Black	0	1
Hispanic	0.028	0.028
Asian	0.031	0.002
Other Race	-0.008	0.14
White	-0.051	<.001
Math θ Wave 1	-0.033	0.152
Math θ Wave 2	-0.006	0.711
Math θ Wave 3	0.075	0.031
Math θ Wave 4	0.005	0.811
Math θ Wave 5	0.081	0.051
Math θ Wave 6	0.003	0.907
Read. θ Wave 1	-0.053	0.021
Read. θ Wave 2	0	0.986
Read. θ Wave 3	0.107	0.004
Read. θ Wave 4	0.023	0.283
Read. θ Wave 5	0.052	0.099
Read. θ Wave 6	0.025	0.21
1st Time K	-0.001	0.852
Age in Months. At Wave 1	-0.57	<.001

Online Appendix C. Models using Sub-sample of Students with Non-Missing Test Scores at Each Wave.

Table C1.
Models Estimating Monthly Rates of Learning (Reference Group Students) and Differences in Monthly Learning Rates by Race/ethnicity and SES, over each School Year and Summer in Fall K SD Units (Top Panel); Models Estimating Monthly Rates of Changes in Standardized Gaps over each School Year and Summer (Bottom Panel), Only Students with Non-Missing Test Scores at Each Wave.

	Math					Reading				
	K	Sum. 1	Gr. 1	Sum. 2	Gr. 2	K	Sum. 1	Gr. 1	Sum. 2	Gr. 2
					ΔT_{SD_1}					
White Students	.16***	.046***	.129***	-.009	.089***	.197***	-.027**	.145***	-.027**	.069***
	(.003)	(.01)	(.002)	(.009)	(.002)	(.004)	(.01)	(.004)	(.008)	(.002)
Black-White	-.006	-.02	-.01~	-.003	-.006	-.014	.045~	-.011~	.019	.004
	(.009)	(.025)	(.005)	(.015)	(.005)	(.014)	(.026)	(.006)	(.014)	(.004)
Hispanic-White	.042***	-.056***	-.009*	-.006	.011**	.013*	.005	-.008~	.027*	.004
	(.006)	(.015)	(.004)	(.014)	(.004)	(.006)	(.014)	(.005)	(.011)	(.003)
Asian-White	-.013	-.002	.012	-.036	.015*	.001	.084***	-.028***	-.003	-.003
	(.009)	(.026)	(.008)	(.025)	(.007)	(.008)	(.021)	(.008)	(.019)	(.005)
90th Pct. SES	.144***	.058***	.133***	-.026**	.087***	.177***	.003	.143***	-.04***	.069***
	(.004)	(.011)	(.003)	(.009)	(.003)	(.004)	(.012)	(.004)	(.01)	(.002)
10th - 90th SES	.044***	-.055***	-.01*	.023~	.01*	.036***	-.033*	-.004	.045***	.002
	(.006)	(.017)	(.005)	(.012)	(.004)	(.006)	(.016)	(.006)	(.013)	(.003)
					ΔG_{ES}					
Black-White	-.027*	.03	-.019**	.018	-.012~	-.024	.082**	-.027**	.034~	-.003
	(.011)	(.032)	(.007)	(.017)	(.007)	(.016)	(.031)	(.009)	(.018)	(.006)
Hispanic-White	.03***	-.028	-.014**	-.005	.011*	.005	.029	-.017*	.017	.002
	(.008)	(.019)	(.005)	(.017)	(.005)	(.008)	(.019)	(.007)	(.014)	(.004)
Asian-White	-.02~	.01	.01	-.023	.018*	-.008	.117***	-.035**	.026	-.003
	(.012)	(.032)	(.008)	(.024)	(.007)	(.01)	(.026)	(.011)	(.022)	(.006)
10th - 90th SES	.022**	-.017	-.012~	.021	.008	.028***	-.028	-.011	.009	-.007
	(.008)	(.02)	(.006)	(.017)	(.005)	(.008)	(.019)	(.008)	(.018)	(.004)

Note. SES=socioeconomic status (continuous composite). Racial/ethnic gaps and SES gaps estimated in separate models (other race – White gaps estimated but not shown). Student-level sample sizes (rounded to nearest 10, as required by NCES): race/ethnicity models n=2770; SES models n=2760. Sampling weight W6CF6P_2B0 applied. Standard errors that account for the complex sampling design are in parentheses. All standardizations adjust for test reliability. Estimates derived from longitudinal model with random intercepts for students, adjusting for time-varying effects of student age at time of fall K assessment and whether student was a first-time kindergartener.
*~p<.10, *p<.05, **p<.01, ***p<.001.*

Online Appendix D. Models Excluding Control Variables

Table D1.

Models Estimating Monthly Rates of Learning (Reference Group Students) and Differences in Monthly Learning Rates by Race/ethnicity and SES, over each School Year and Summer in Fall K SD Units (Top Panel); Models Estimating Monthly Rates of Changes in Standardized Gaps over each School Year and Summer (Bottom Panel), No Age/1st Time K Controls.

	Math					Reading				
	K	Sum. 1	Gr. 1	Sum. 2	Gr. 2	K	Sum. 1	Gr. 1	Sum. 2	Gr. 2
	ΔT_{SD_1}									
White Students	.162***	.068***	.124***	-.001	.086***	.199***	-.001	.137***	-.007	.067***
	(.002)	(.013)	(.004)	(.009)	(.003)	(.003)	(.016)	(.005)	(.008)	(.002)
Black-White	.011**	-.029	-.017**	.012	-.005	-.007~	.015	-.009	.022	-.005
	(.004)	(.018)	(.005)	(.013)	(.004)	(.004)	(.019)	(.006)	(.014)	(.004)
Hispanic-White	.041***	-.072***	-.003	-.021	.016**	.014**	.001	-.003	.012	.004
	(.004)	(.018)	(.004)	(.018)	(.006)	(.004)	(.019)	(.005)	(.014)	(.004)
Asian-White	-.01*	-.024	.009	.015	.008	-.01~	.051*	-.014*	.001	-.007
	(.004)	(.024)	(.008)	(.015)	(.005)	(.006)	(.022)	(.006)	(.02)	(.007)
90th Pct. SES	.143***	.088***	.124***	-.004	.085***	.18***	.017	.135***	-.022*	.065***
	(.002)	(.012)	(.003)	(.009)	(.003)	(.002)	(.014)	(.005)	(.009)	(.003)
10th - 90th SES	.052***	-.082***	-.002	-.005	.012*	.037***	-.019	-.003	.041***	.002
	(.004)	(.014)	(.004)	(.012)	(.005)	(.005)	(.016)	(.005)	(.011)	(.003)
	ΔG_{ES}									
Black-White	-.006	.014	-.024***	.029~	-.012*	-.014**	.055*	-.022***	.028~	-.015**
	(.005)	(.023)	(.007)	(.015)	(.005)	(.005)	(.021)	(.006)	(.015)	(.005)
Hispanic-White	.027***	-.03	-.006	-.017	.014*	.007	.045*	-.015**	.004	-.001
	(.005)	(.018)	(.005)	(.021)	(.006)	(.005)	(.019)	(.006)	(.018)	(.005)
Asian-White	-.012*	-.005	.004	.034~	.007	-.013*	.086***	-.022***	.026	-.011
	(.005)	(.026)	(.009)	(.02)	(.006)	(.006)	(.02)	(.006)	(.023)	(.008)
10th - 90th SES	.027***	-.046**	0	-.01	.008~	.024***	.006	-.013**	.011	-.008~
	(.005)	(.017)	(.005)	(.014)	(.005)	(.006)	(.018)	(.005)	(.012)	(.004)

Note. SES=socioeconomic status (continuous composite). Racial/ethnic gaps and SES gaps estimated in separate models (other race – White gaps estimated but not shown). Standard errors that account for the complex sampling design are in parentheses. All standardizations adjust for test reliability. Estimates derived from longitudinal model with random intercepts for students.
*~p<.10, *p<.05, **p<.01, ***p<.001.*

Online Appendix E. Time Period Variables

The ECLS-K:2011 includes variables indicating the month and day of students' first and last days of school for each school year (X*SCHBMM, X*SCHBDD, X*SCHEMM, X*SCHEDD). For each test wave, the restricted-use version of the data includes a variable giving the month of the assessment (X*ASMTMM) along with the 7-day window of that month that the student took the assessment (X*ASMTDD). We use these sets of variables in order to determine how many days of K, summer 1, grade 1, summer 2, and grade 2 each student had experienced at each test wave. Because students' exact test dates are not reported, the *MONTHS* variables (described in the main text) are measured with some error. For each test wave, we assigned students the mid-point of the 7-day window as their test date.

Online Appendix F. Estimation of SES Gap Dynamics.

We use the estimated coefficients from model 1 of the main text to obtain, for each season, an estimate of the mean difference in monthly academic growth rates between students from the 10th and 90th percentiles of the SES distribution:

$$\Delta\hat{T}_{SD1}^{(rate)}{}_{Period\ P}^{(10th\ SES-90th\ SES)} = \left(\hat{\tau}^{(P\times SES)} \times SES_{10th}\right) - \left(\hat{\tau}^{(P\times SES)} \times SES_{90th}\right)$$

where $\hat{\tau}^{(P\times SES)}$ is the coefficient on the interaction term between SES and the relevant time period and $SES_{10th}$and SES_{90th} are values for the 10th and 90th percentiles of the sample distribution of SES.

Online Appendix G. Longitudinal Piecewise Linear Regression Models (Unadjusted for Test Date).

In these supplementary analyses, we estimate racial/ethnic and SES gap changes using piecewise longitudinal models of the form:

$$\text{(G1) } Y_{it} = \alpha_i + \sum_r \beta_r \, RACE_i + \sum_w \beta_w \, WAVE_t + \sum_k \beta_k \, (WAVE_t \times RACE_i) + \sum_n \pi_n C_i + \sum_l \lambda_l (C_i \times WAVE_t) + \epsilon_{it}$$

$$\epsilon_{it} \sim N(0, \sigma_y^2) \perp \alpha_i \sim N(\mu_\alpha, \sigma_\alpha^2)$$

where *i* indexes student and *t* indexes time, α_i represents a student-specific random intercept, $\sum_r \beta_r \, RACE_i$ is a set of mutually exclusive racial/ethnic dummy variables (non-Hispanic Black, Hispanic, or Asian, with non-Hispanic Whites as the reference group), $\sum_w \beta_w \, WAVE_t$ is a set of "switch" indicator variables that turn on (i.e. go from equaling 0 to equaling 1) when $t \geq w$, $(WAVE_t \times RACE_i)$ is a set of interactions between race and the wave "switch" variables, and $\sum_n \pi_n C_i$ is the set of controls described in the main text. Coefficients on the race×wave interaction terms represent gap changes over each period. Results are shown in Table G1.

Table G1.

Models Estimating Total Learning (Reference Group Students) and Total Differences in Learning by Race/ethnicity and SES between each Test (Unadjusted for Test Date) in Fall K SD Units (Top Panel); Models Estimating Total Changes in Standardized Gaps between each Test (Unadjusted for Test Date; Bottom Panel).

	Math					Reading				
	K	Sum. 1	Gr. 1	Sum. 2	Gr. 2	K	Sum. 1	Gr. 1	Sum. 2	Gr. 2
					ΔT_{SD_1}					
White Students	.989***	.551***	.847***	.269***	.601***	1.2***	.433***	.951***	.248***	.467***
	(.018)	(.026)	(.024)	(.017)	(.017)	(.02)	(.026)	(.024)	(.017)	(.019)
Black-White	.046	-.037	-.149***	.018	-.057~	-.055~	.091*	-.128**	.046~	-.037
	(.028)	(.042)	(.038)	(.029)	(.031)	(.03)	(.044)	(.038)	(.023)	(.027)
Hispanic-White	.207***	-.027	-.1**	.017	.05~	.063~	.117***	-.115***	.075**	-.009
	(.027)	(.036)	(.03)	(.03)	(.03)	(.037)	(.035)	(.028)	(.024)	(.026)
Asian-White	-.135***	.007	-.006	.107**	-.007	-.112**	.174***	-.178***	.028	-.1*
	(.027)	(.052)	(.049)	(.035)	(.036)	(.036)	(.033)	(.029)	(.043)	(.045)
90th Pct. SES	.862***	.589***	.832***	.269***	.583***	1.067***	.48***	.906***	.224***	.438***
	(.016)	(.027)	(.023)	(.017)	(.016)	(.016)	(.027)	(.026)	(.018)	(.019)
10th - 90th SES	.314***	-.094*	-.047	.019	.051~	.237***	.03	-.044	.099***	.02
	(.027)	(.038)	(.035)	(.023)	(.027)	(.033)	(.034)	(.031)	(.02)	(.022)
					ΔG_{ES}					
Black-White	-.053~	-.008	-.145***	.014	-.086*	-.088**	.103*	-.158***	-.008	-.071*
	(.03)	(.047)	(.043)	(.032)	(.034)	(.03)	(.047)	(.04)	(.03)	(.035)
Hispanic-White	.122***	-.002	-.092**	.012	.04	.021	.132***	-.148***	.021	-.036
	(.028)	(.041)	(.034)	(.033)	(.032)	(.038)	(.037)	(.03)	(.03)	(.03)
Asian-White	-.109***	-.002	-.008	.118**	-.001	-.095*	.187***	-.186***	.045	-.111*
	(.027)	(.058)	(.056)	(.038)	(.04)	(.037)	(.036)	(.031)	(.047)	(.051)
10th - 90th SES	.153***	-.049	-.021	.012	.027	.154***	.04	-.089**	-.007	-.04
	(.027)	(.043)	(.039)	(.025)	(.03)	(.034)	(.036)	(.033)	(.024)	(.025)

Note. Sampling weight W1C0 applied. Standard errors that account for the complex sampling design are in parentheses. SES=socioeconomic status (continuous composite). Racial/ethnic gaps and SES gaps estimated in separate models (other race – White gaps estimated but not shown). All standardizations adjust for test reliability. Estimates derived from longitudinal model with random intercepts for students, incorporating all available test data and adjusting for time-varying effects of student age at time of fall K assessment and whether student was a first-time kindergartener.

*~p<.10, *p<.05, **p<.01, ***p<.001.*

Online Appendix H. Descriptive Statistics by Test Wave

		Overall			Black			Hispanic			Asian			White		
Variable	Wave	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Math/SD																
1	Fall K	-0.524	1.028	11280	-0.871	0.974	1330	-1.004	1.086	2800	-0.082	0.955	810	-0.262	0.905	5710
	Spr. K	0.508	0.863	11300	0.137	0.901	1330	0.2	0.874	2810	0.77	0.806	830	0.711	0.783	5710
	Fall 1st	1.002	0.921	3750	0.653	0.824	360	0.72	0.821	1350	1.322	0.886	290	1.286	0.921	1520
	Spr. 1st	1.86	0.949	11120	1.379	0.827	1300	1.481	0.88	2730	2.159	0.866	840	2.116	0.904	5640
	Fall 2nd	2.09	0.925	3630	1.657	0.861	340	1.775	0.878	1310	2.521	0.792	280	2.408	0.855	1480
	Spr. 2nd	2.746	0.901	11040	2.202	0.885	1290	2.432	0.875	2710	3.146	0.776	830	2.976	0.819	5610
Math																
(std.)	Fall K	0.06	1.028	11280	-0.288	0.974	1330	-0.42	1.086	2800	0.502	0.955	810	0.322	0.905	5710
	Spr. K	0.044	1.024	11300	-0.398	1.069	1330	-0.322	1.038	2810	0.354	0.957	830	0.284	0.93	5710
	Fall 1st	0.035	1.033	3750	-0.357	0.925	360	-0.282	0.92	1350	0.393	0.994	290	0.354	1.033	1520
	Spr. 1st	0.032	1.034	11120	-0.493	0.902	1300	-0.381	0.96	2730	0.358	0.945	840	0.31	0.986	5640
	Fall 2nd	0.038	1.017	3630	-0.438	0.946	340	-0.309	0.965	1310	0.512	0.87	280	0.386	0.939	1480
	Spr. 2nd	0.021	1.018	11040	-0.594	0.999	1290	-0.334	0.988	2710	0.473	0.876	830	0.28	0.926	5610
Reading/																
SD1	Fall K	-0.631	1.029	11340	-0.797	0.973	1340	-1.039	1.01	2790	-0.214	1.183	850	-0.439	0.97	5730
	Spr. K	0.568	0.933	11330	0.35	0.956	1330	0.239	0.994	2810	0.854	1.02	850	0.747	0.832	5710
	Fall 1st	1.029	0.947	3740	0.861	0.931	360	0.791	0.9	1330	1.522	0.984	290	1.223	0.923	1520
	Spr. 1st	1.952	0.914	11120	1.702	0.879	1300	1.619	0.918	2730	2.252	0.83	840	2.133	0.863	5640
	Fall 2nd	2.202	0.812	3630	1.992	0.757	340	1.955	0.765	1310	2.528	0.651	280	2.427	0.8	1470
	Spr. 2nd	2.675	0.769	11050	2.417	0.725	1290	2.407	0.776	2710	2.908	0.679	830	2.835	0.728	5610
Reading	Fall K	0.046	1.029	11340	-0.121	0.973	1340	-0.363	1.01	2790	0.462	1.183	850	0.237	0.97	5730

(std.)															
	Spr. K	0.041	1.017	11330	-0.198	1.042	1330	-0.319	1.084	2810	0.352	1.112	850	0.235	0.908	5710
	Fall 1st	0.034	1.026	3740	-0.149	1.008	360	-0.224	0.974	1330	0.568	1.066	290	0.244	0.999	1520
	Spr. 1st	0.034	1.029	11120	-0.247	0.991	1300	-0.341	1.034	2730	0.373	0.936	840	0.238	0.973	5640
	Fall 2nd	0.043	1.028	3630	-0.223	0.958	340	-0.269	0.968	1310	0.456	0.824	280	0.328	1.012	1470
	Spr. 2nd	0.03	1.034	11050	-0.317	0.974	1290	-0.331	1.043	2710	0.342	0.913	830	0.244	0.978	5610
Months K	Fall K	1.886	0.828	11400	1.963	0.781	1340	1.886	0.845	2830	2.01	0.828	860	1.87	0.829	5740
	Spr. K	7.834	0.713	11340	7.939	0.677	1340	7.811	0.74	2810	7.73	0.745	850	7.833	0.704	5720
	Fall 1st	9.439	0.256	3760	9.495	0.219	360	9.445	0.287	1350	9.465	0.184	290	9.437	0.237	1520
	Spr. 1st	9.398	0.264	11130	9.452	0.203	1300	9.444	0.268	2730	9.442	0.218	840	9.365	0.273	5650
	Fall 2nd	9.441	0.257	3630	9.499	0.221	340	9.448	0.289	1310	9.466	0.183	280	9.438	0.237	1480
	Spr. 2nd	9.398	0.264	11060	9.453	0.202	1290	9.444	0.269	2710	9.443	0.217	830	9.365	0.273	5620
Mo. Sum. 1	Fall K	0	0	11400	0	0	1340	0	0	2830	0	0	860	0	0	5740
	Spr. K	0.001	0.02	11340	0.002	0.033	1340	0.002	0.031	2810	0	0	850	0	0.008	5720
	Fall 1st	2.505	0.231	3760	2.488	0.233	360	2.482	0.231	1350	2.459	0.184	290	2.514	0.226	1520
	Spr. 1st	2.582	0.277	11130	2.553	0.227	1300	2.516	0.266	2730	2.538	0.2	840	2.618	0.291	5650
	Fall 2nd	2.506	0.243	3630	2.487	0.235	340	2.484	0.261	1310	2.461	0.182	280	2.514	0.226	1480
	Spr. 2nd	2.582	0.277	11060	2.553	0.227	1290	2.517	0.266	2710	2.538	0.197	830	2.617	0.292	5620
Months Gr 1	Fall K	0	0	11400	0	0	1340	0	0	2830	0	0	860	0	0	5740
	Spr. K	0	0	11340	0	0	1340	0	0	2810	0	0	850	0	0	5720
	Fall 1st	1.635	0.769	3760	1.764	0.619	360	1.736	0.79	1350	1.506	0.712	290	1.541	0.783	1520
	Spr. 1st	7.843	0.709	11130	7.943	0.693	1300	7.864	0.728	2730	7.751	0.75	840	7.818	0.697	5650

	Fall 2nd	9.376	0.307	3630	9.387	0.235	340	9.382	0.282	1310	9.435	0.267	280	9.377	0.351	1480
	Spr. 2nd	9.327	0.279	11060	9.377	0.204	1290	9.375	0.264	2710	9.397	0.23	830	9.29	0.302	5620
Mo. Sum. 2	Fall K	0	0	11400	0	0	1340	0	0	2830	0	0	860	0	0	5740
	Spr. K	0	0	11340	0	0	1340	0	0	2810	0	0	850	0	0	5720
	Fall 1st	0	0	3760	0	0	360	0	0	1350	0	0	290	0	0	1520
	Spr. 1st	0	0.009	11130	0	0.003	1300	0.001	0.015	2730	0	0.005	840	0	0.007	5650
	Fall 2nd	2.528	0.367	3630	2.559	0.238	340	2.486	0.393	1310	2.443	0.355	280	2.547	0.376	1480
	Spr. 2nd	2.628	0.325	11060	2.58	0.226	1290	2.556	0.344	2710	2.555	0.309	830	2.676	0.332	5620
Months Gr 2	Fall K	0	0	11400	0	0	1340	0	0	2830	0	0	860	0	0	5740
	Spr. K	0	0	11340	0	0	1340	0	0	2810	0	0	850	0	0	5720
	Fall 1st	0	0	3760	0	0	360	0	0	1350	0	0	290	0	0	1520
	Spr. 1st	0	0	11130	0	0	1300	0	0	2730	0	0	840	0	0	5650
	Fall 2nd	1.628	0.753	3630	1.75	0.658	340	1.671	0.815	1310	1.512	0.718	280	1.595	0.734	1480
	Spr. 2nd	7.976	0.63	11060	8.062	0.589	1290	7.994	0.665	2710	7.864	0.639	830	7.959	0.619	5620
SES	Fall K	-0.035	0.809	10530	-0.369	0.714	1200	-0.525	0.717	2540	0.342	0.892	770	0.224	0.729	5430
1st Time K	Fall K	0.949	0.22	11400	0.925	0.263	1340	0.943	0.232	2830	0.953	0.211	860	0.955	0.208	5740
Age (mo.) Fall K	Fall K	67.585	4.464	11400	67.328	4.694	1340	66.99	4.255	2830	66.249	4.318	860	68.034	4.488	5740

Note. Sample weight W1C0 applied. Sample sizes rounded to the nearest 10, as required by the NCES. Sample sizes by race do not sum to overall because "other race" subgroup is included in the overall descriptive statistics (and models).

Online Appendix I. Attrition Sensitivity Checks.

As with most longitudinal research, non-random sample attrition may bias our results. We know that students who are missing a test score in one particular wave have, on average, lower scores in other waves compared to students who were not missing a test score for the original wave in question. To approximate a lower bound on potential bias, we conducted supplementary analyses in which we imputed low scores for students at any wave for which they were missing outcome data. Specifically, we assigned students scores at the 10^{th} percentile of the observed score distribution for any wave for which they were missing data and included those imputed scores in a new model. For rounds 3 and 5 (when only a subsample of students were tested), we imputed outcome scores for non-sampled students based on an imputation model including all previous test scores and the variables in the main models, and assigned these students sample mean values for the time period variables. These results, shown in Table I1, are quite similar to those in the main text, given the small number of students in the analytic sample who attritted (temporarily or permanently).

Table I1. Attrition Sensitivity Analyses: Models Imputing Low Scores for Attriters.

Models Estimating Monthly Rates of Learning (Reference Group Students) and Differences in Monthly Learning Rates by Race/ethnicity and SES, over each School Year and Summer in Fall K SD Units (Top Panel); Models Estimating Monthly Rates of Changes in Standardized Gaps over each School Year and Summer (Bottom Panel). Models Impute Low Scores for Attritters.

	Math					Reading				
	K	Sum. 1	Gr. 1	Sum. 2	Gr. 2	K	Sum. 1	Gr. 1	Sum. 2	Gr. 2
					ΔT_{SD_1}					
White Students	.162***	.032***	.137***	-.083***	.113***	.197***	-.049***	.154***	-.05***	.081***
	(.002)	(.006)	(.002)	(.011)	(.004)	(.003)	(.008)	(.003)	(.006)	(.002)
Black-White	.014**	-.021	-.02***	-.005	-.002	-.006	.037*	-.016*	.021	-.005
	(.005)	(.015)	(.005)	(.025)	(.008)	(.004)	(.015)	(.007)	(.015)	(.005)
Hispanic-White	.041***	-.055***	-.007*	-.024	.015*	.017***	.013	-.009*	.019~	.001
	(.005)	(.016)	(.003)	(.019)	(.006)	(.005)	(.015)	(.004)	(.01)	(.003)
Asian-White	.009	-.001	.013*	-.039	.019**	-.01~	.087***	-.027***	.003	-.008*
	(.009)	(.022)	(.006)	(.024)	(.007)	(.006)	(.016)	(.005)	(.013)	(.004)
90th Pct. SES	.141***	.036***	.142***	-.11***	.117***	.176***	-.033**	.152***	-.08***	.083***
	(.002)	(.009)	(.003)	(.015)	(.005)	(.002)	(.01)	(.004)	(.009)	(.002)
10th - 90th SES	.059***	-.034**	-.016***	.032~	.002	.042***	.001	-.01*	.071***	-.006*
	(.004)	(.012)	(.004)	(.017)	(.006)	(.005)	(.013)	(.004)	(.011)	(.003)
					ΔG_{ES}					
Black-White	-.008	.019~	-.024***	.032***	-.014***	-.014**	.072***	-.028***	.031***	-.015***
	(.005)	(.011)	(.004)	(.007)	(.003)	(.005)	(.011)	(.005)	(.008)	(.004)
Hispanic-White	.024***	-.026~	-.008*	-.007	.01**	.006	.053***	-.019***	.013	-.004
	(.005)	(.015)	(.003)	(.01)	(.003)	(.005)	(.014)	(.004)	(.009)	(.003)
Asian-White	-.015**	.004	0	.023**	.007~	-.015*	.111***	-.032***	.034**	-.014**
	(.005)	(.011)	(.005)	(.008)	(.004)	(.006)	(.011)	(.004)	(.011)	(.004)
10th - 90th SES	.028***	-.01	-.011**	.014*	.002	.025***	.019	-.017***	.034***	-.014***
	(.005)	(.011)	(.004)	(.007)	(.003)	(.006)	(.012)	(.003)	(.006)	(.002)

Note. Sampling weight W1C0 applied. Standard errors that account for the complex sampling design are in parentheses. SES=socioeconomic status (continuous composite). Racial/ethnic gaps and SES gaps estimated in separate models (other race – White gaps estimated but not shown). All standardizations adjust for

test reliability. Estimates derived from longitudinal model with random intercepts for students, incorporating all available test data, imputing low scores for (temporary and permanent) attritters, and adjusting for time-varying effects of student age at time of fall K assessment and whether student was a first-time kindergartener.
*~p<.10, *p<.05, **p<.01, ***p<.001.*

Online Appendix J. Estimation of School Entry Gaps and Net Gap Changes.

To estimate gaps at K entry, and net gap changes from fall of K to spring of 2nd (Table 2 of main text), we fit versions of the following general model:

(J1) $$Y_{it} = \alpha_i + \sum_r \beta_r\, RACE_i + \sum_w \beta_w\, WAVE_t + \sum_k \beta_k\, (WAVE_t \times RACE_i) + \sum_n \pi_n C_i + \sum_l \lambda_l (C_i \times WAVE_t) + \epsilon_{it}$$

$$\epsilon_{it} \sim N\left(0,\, \sigma_y^2\right) \perp \alpha_i \sim N\left(\mu_\alpha,\, \sigma_\alpha^2\right)$$

where *i* indexes student and *t* indexes time, α_i represents a student-specific random intercept, $\sum_r \beta_r\, RACE_i$ is a vector of mutually exclusive racial/ethnic dummy variables (non-Hispanic Black, Hispanic, or Asian, with non-Hispanic Whites as the reference group), $\sum_w \beta_w\, WAVE_t$ is a vector of indicators for test wave (with wave 1 as the omitted indicator), $\sum_k \beta_k\, (WAVE_t \times RACE_i)$ is a vector of race×wave interactions, and $\sum_n \pi_n C_i$ includes the control variables described in the main text.

When $Y_{it} = \frac{\theta_{it}}{\sqrt{r_1} \times SD_1}$, the coefficients on the interaction terms between the race/ethnicity indicators and the wave 6 indicator represent $\Delta T_{SD_1}^{(K-2)}$, or the total difference in growth between the indicated racial/ethnic group and Whites between fall of K and spring of second grade (expressed in wave 1 SD units). When $Y_{it} = \frac{\theta_{it} - \overline{\theta_t}}{\sqrt{r_t} \times SD_t}$, the same interaction terms represent $\Delta G_{ES}^{(K-2)}$, or the total change in standardized gap. In both cases, the coefficients on the race/ethnicity indicators represent the fall of K gaps.

We estimate $\Delta T_{SD_1}^{(K-2)}$ and $\Delta G_{ES}^{(K-2)}$between students from the 10th and 90th percentiles of the SES distribution using a model similar to model J1, except that we remove the vector of race/ethnicity dummies and their associated interactions, and add the continuous SES composite variable and a vector of interactions between the SES term and the $WAVE_t$ variables. Using the

parameter estimates, we plug in values for the 10^{th} and 90^{th} percentiles of the sample SES distribution to obtain estimates of gaps and gap dynamics.

Online Appendix K. Changes in Racial/ethnic *V* Gaps between each Test, and Overall from K-2 (Analytic Sample from Main Text).

Table K1.
Changes in Racial/ethnic V-Gaps between each Test and Overall.

	Reading			Math		
Change over period:	Black-White	Hispanic-White	Asian-White	Black-White	Hispanic-White	Asian-White
K	-0.069	0.063	-0.046	-0.061	0.118	-0.121
Summer 1	0.047	0.078	0.162	-0.009	-0.015	-0.061
Grade 1	-0.117	-0.111	-0.162	-0.152	-0.078	0.017
Summer 2	-0.064	-0.019	-0.038	-0.047	-0.057	0.093
Grade 2	-0.021	0.026	-0.006	-0.042	0.114	0.115
Total, Fall K to Spr. Gr. 2	-0.224	0.037	-0.090	-0.311	0.082	0.044