Redrawing attendance boundaries to promote racial and ethnic diversity in elementary schools

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Abstract

Most US school districts draw "attendance boundaries" to define catchment areas that assign students to schools near their homes, often recapitulating neighborhood demographic segregation in schools. Focusing on elementary schools, we ask: how much might we reduce school segregation by redrawing attendance boundaries? Combining parent preference data with methods from combinatorial optimization, we simulate alternative boundaries for 98 US school districts serving over 3 million elementary-aged students, minimizing White/non-White segregation while mitigating changes to travel times and school sizes. Across districts, we observe a median 12% relative decrease in segregation, which we estimate would require nearly 20% of students to switch schools and, surprisingly, a slight *reduction* in travel times. We release a public dashboard depicting these alternative boundaries (www.schooldiversity.org) and invite both school boards and their constituents to evaluate their viability. Our results show the possibility of greater integration without significant disruptions for families.

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Introduction

It has been over 65 years since the US Supreme Court ordered the racial desegregation of schools ("Brown v. Board of Education of Topeka (1)," n.d.). Yet segregation by race and income in K12 schools continues to hamper access to quality education for millions of children across the US (Reardon et al., 2018), despite strong evidence that integration reduces achievement gaps between lower income students of color and their more affluent, majority race counterparts (Billings et al., 2013; Johnson, 2011; Wells & Crain, 1994). Of course, increasing diversity by fostering more demographic integration is not a foolproof method for reducing achievement gaps. Too often, even after addressing segregation at the school level, segregation persists at the classroom or friendship level (Card & Giuliano, 2016; Moody, 2001; Potter, 2016; Tatum, 1997), or low income students of color feel unsupported in more integrated environments (Comer, 1988). Diversity done wrong can cause more harm than good. And yet, more diverse schools can serve as a necessary first step toward providing children from different racial and socioeconomic backgrounds the chance to mix and learn from one another. This learning and mixing is important beyond its potential role in reducing achievement gaps: it can also help increase empathy, compassion, reflective thought (Wells et al., 2016), and encourage more welcoming attitudes towards diversity later on in life (Davies et al., 2011; Wells & Crain, 1994). There is evidence to suggest that all students can benefit from racially and socioeconomically diverse classrooms.

Yet across the US, the vast majority of students attend the schools closest to their homes by virtue of how "school attendance boundaries"—or catchment areas—are drawn (Monarrez, 2021; Richards, 2014; Saporito & Riper, 2016), leading schools to recapitulate neighborhood-level segregation by race and income. The expansion of school choice programs has sought to challenge the geographic determinism of boundary-driven school assignment and thereby also mitigate school segregation (Kahlenberg, 2016). However, choice too, has been shown in several instances to perpetuate segregation due to self-selection of certain families into certain schools (Candipan, 2019; Monarrez et al., 2022; Whitehurt, 2017). Boundaries continue to play a prominent role in student assignment: as of 2016, approximately 20% of students in grades 1-12 participated in some type of public school choice (including 8% opting for charter schools); 9% attended private schools; and the remaining 71% attended an assigned school, likely determined by geography (of Education, 2021). Choice programs have continued to gain popularity in recent years, particularly as some subsets of families have sought new avenues for mitigating the pandemic's effects on their children's learning (Houlgrave, 2021), yet place-based school assignment continues to be the norm. Even in choice settings, where students live might influence the priority they are assigned to attend a certain schools (Monarrez & Chien, 2021), or even which schools are part of the choice set (Campos & Kearns, 2022). This makes attendance boundaries, and more generally, place of residence a perennially important factor in school attendance policies. The implications of these boundaries and resultant segregation can run deep: for example, they have been shown to demarcate stark gradients in access to gifted and talented programs, quality teachers, school counselors, and a number of other educational resources (Monarrez & Chien, 2021).

Despite the impact attendance boundaries can have on socioeconomic diversity in schools, most school segregation results from how the lines *between* districts are drawn (e.g. separating cities from suburbs), instead of school-specific boundaries *within* districts (Fiel, 2013; Monarrez, 2021). Redrawing district boundaries is arguably a more difficult problem, however, because it falls under the purview of state legislatures—making it subject to the whims, frictions, and bureaucratic inefficiencies of similarly-contentious political issues manifesting at state and federal levels. On the other hand, changing attendance boundaries within districts generally falls under the purview of those districts. Indeed, a landmark 2007 Supreme Court case outlawed the use of individual students' racial backgrounds as an input into school desegregation efforts and effectively encouraged districts to explore the redrawing of school attendance boundaries as a desegregation policy (Totenberg, 2007). Yet even within districts, changing boundaries continues to be a highly contentious topic, especially when issues of diversity are also at stake (McMillan, 2018). Parents may fear that rezoning students will increase travel times through longer "busing" (Frankenberg & Jacobsen, 2011), reduce quality of education (Zhang, 2008)—which they often define vis-á-vis test scores (Abdulkadiroglu et al., 2019) and class sizes (Gilraine et al., 2018), produce unsafe school environments (Staff, 2019), drop property values (Black, 1999; Bridges, 2016; Kane et al., 2005), fragment communities (Bridges, 2016; Staff, 2019), and require a number of other sacrifices.

These concerns, while sometimes reasonable, often impede practical paths towards achieving more diverse and integrated schools—e.g., by sparking "white flight" in response to unfavorable school assignment policies (Reber, 2005) and souring public opinion towards desegregation efforts as a result of concerns about long-distance busing and other inconveniences (Delmont, 2016). Furthermore, despite parents increasingly expressing support for school integration through polls and surveys (Frankenberg & Jacobsen, 2011; Torres & Weissbourd, 2020), they continue to "vote with their feet", deciding where to live and send their children to school in ways that reflect racialized preferences (Billingham & Hunt, 2016; Charles, 2003; Hailey, 2021; Hall & Hibel, 2017; Iceland et al., 2010). Such preferences, especially when aggregated and compounded across families, can yield extreme levels of segregation across neighborhoods, cities, and schools (Card et al., 2008; Schelling, 1971). Shifting these underlying preferences is one of the greatest challenges of our time, and is critical for the implementation of sustainable school desegregation efforts that persist in the face of changing legal mandates (Billings et al., 2013). Alongside this deeper work, however, it is also critical to identify if there are pathways to achieving more diverse and integrated schools *today*—in the case of our focus, through alternative attendance boundaries—that families may earnestly consider and not immediately dismiss because they significantly disrupt and decrease day-to-day quality of life.

The purpose of this paper is to explore to what extent this is the case, i.e., if it is possible to redraw attendance boundaries within districts in order to achieve more diverse schools without requiring families from different racial and ethnic backgrounds to make large sacrifices. While several studies have explored relationships between attendance boundaries and school segregation (Monarrez, 2021; Richards, 2014; Saporito & Riper, 2016), we have found few that have explored actually changing school boundaries—with the exception of (Caro et al., 2004; Clark & Surkis, 1968; Liggett, 1973; Mota et al., 2021)—yet these have not focused on achieving greater racial and ethnic diversity across schools as the main objective of their approach. Larger districts may hire external vendors to explore alternative boundary scenarios; however, their exact tools and methods are often opaque, and diversity is rarely, if ever, a primary objective—though it is sometimes included as a constraint or post hoc measure ("Montgomery County Public Schools Districtwide Boundary Analysis," 2021). To our knowledge, our work is the first to simulate alternative attendance boundaries optimized to achieve racial and ethnic desegregation across a large number of US school districts. Simulations alone are not sufficient to drive policy change, especially in the face of parents and others who might oppose such change, but may help illuminate possible paths to integration "within reach" that both districts and families may not have previously explored.

We frame our inquiry as an constrained optimization problem and ask two overarching questions: 1) how can we re-assign geographies to schools in order to minimize racial segregation, defined as imbalances in the White/non-White composition at schools relative to district-level proportions, while respecting parents' travel time and class size preferences? And 2) how fairly are these reductions in segregation, and associated costs—namely, changes in travel times and school switching requirements—distributed across Asian, Black, Hispanic/Latinx, Native American, and White students? To explore these questions, we focus on elementary schools for similar reasons as (Monarrez, 2021):

because their boundaries often approximately combine to form the boundaries of the middle and high schools they "feed" to, and hence, are foundational in shaping diverse exposures at an early age. We use parent input and computational tools to simulate changes across 98 large school districts across the US with district elementary schools that are classified as non open-enrollment: that is, attendance at these schools are entirely a function of which neighborhoods are zoned to attend them. These schools collectively serve over 3 million students.

We focus on White/non-White segregation as our primary quantity of interest given its historical significance within the US and abroad; its association with other family-level factors that have been shown to correlate with educational outcomes, like socioeconomic status (Reardon et al., 2018); and the precision and reliability with which racial/ethnic data is available at the granularity of schools and small geographic units like Census blocks (as opposed to measures of socioeconomic status among parents, which are also critical in the discussion about school segregation, but less reliably and precisely defined and available (Harwell & LeBeau, 2010)). White/non-White segregation does not perfectly capture patterns of segregation across all school districts: for example, in some district settings, White and Asian students may be more likely to attend schools together, segregated away from their Black and Hispanic/Latinx counterparts (Chang, 2018). Nevertheless, across most districts, including those in our sample, White, Black, and Hispanic/Latinx students constitute the vast majority of the population, rendering White/non-White segregation an important dimension of analysis.

Our findings show that alternative attendance boundaries could produce a relative decrease of 12% in White/non-White segregation across districts. These boundaries would require nearly 20% of students to switch schools, and interestingly, a slight *decrease* of just under one minute in these students' time spent traveling to school. On average, these "costs" of added diversity appear to be fairly distributed across different student groups, though through two case studies, we see that this can vary by district and rezoning. We release our code and several datasets, inviting interested researchers and school districts across the US to further explore the opportunities and potential trade-offs involved in changing attendance boundaries to advance integration in their own districts. Below, we describe our approach, key results, limitations, and potential avenues for future work.

Data and Methods

Optimization model

We use the dissimilarity index (Massey & Denton, 1988) as our primary measure of segregation. The index is defined as:

$$\frac{1}{2}\ \Sigma_{s \in S}\ |\frac{W_s}{W_T} - \frac{NW_s}{NW_T}| \tag{1}$$

Where s is an elementary school across all district elementary schools S; W_s and NW_s correspond to the number of White and non-White students at s, and W_T and NW_T to the total number of White and non-White students across the district, respectively. Perfectly integrated districts—where the proportion of White/non-White students in each school reflects district-wide proportions—would receive a score of 0 under this measure, while perfectly segregated districts would receive a score of 1. Intuitively, the dissimilarity index indicates the proportion of White students in the district who would need to switch schools in order to achieve perfect integration (Jakubs, 1977).

It is important to note that scholars have proposed a myriad of school segregation measurements over the past several decades, many of which seek to overcome several potential shortcomings of the dissimilarity index. Some of these shortcomings include its 1) failure to fully respect the "transfers/exchanges" principle, whereby movement of students from schools with a higher proportion of other same-race students to a school with a lower proportion may not decrease dissimilarity unless one school is over-represented, and the other under-represented, with respect to the group's district-wide prevalence (James & Taeuber, 1985); and 2) potential equal treatment of changes that lower the index, even if some may have more normative value than others (like reducing a school's demographic population of 100% to 90% belonging to a certain group, vs. 60% to 50%) (Winship, 1978). Nevertheless, for the purposes of this preliminary investigation, we choose this index over others because of its 1) simplicity and widespread recognition; 2) extensive use in prior literature, including studies of school segregation (James & Taeuber, 1985; Monarrez et al., 2019); and 3) general agreement with levels of segregation computed in other studies (Monarrez et al., 2019, 2022) when compared to some alternative measures like the variance ratio index (Massey & Denton, 1988; Owens et al., 2022).

Still, there are many other valid measures that each capture slightly different notions of both levels of segregation and diversity across schools, including multi-group measures like Theil's Entropy Index (Reardon & Firebaugh, 2002), and the aforementioned variance ratio index, which seeks to simultaneously quantify both measures of evenness (similar to the dissimilarity index) and exposure. An important and exciting direction for future work is a more thorough exploration of these and other alternative measures. To support these efforts, we include documentation as a part of our code release that describes how researchers can make minor modifications to our framework in order to implement and evaluate alternative metrics. Critically, we note that all of these measures of segregation are naive in that they do not account for within-school segregation and sorting (Moody, 2001; Tatum, 1997)—including levels of "friending bias" (Chetty et al., 2022) that may manifest within schools and subsequently affect who connects with whom, how social capital is shared, and ultimately the extent to which more diverse schools translate into more engagement across lines of difference.

With these considerations in hand, we design a rezoning algorithm which seeks to re-assign Census blocks to elementary schools within each district in order to minimize Equation 1. Rezoning problems are generally computationally challenging because of the many geographic units they operate over, and the sometimes large number of constraints (e.g., in the case of contiguity constraints) they impose. Much redistricting work to date has focused on congressional redistricting, and many approaches to this have used mixed-integer programming (MIP) as a core building block (Becker & Solomon, 2020), often augmented with problem-specific search strategies (Gurnee & Shmoys, 2021). To compute these combinatorial optimization problems—which are “NP-hard” and lack efficient, polynomial time solutions—we use constraint programming (Van Hentenryck, 1989) via the CP-SAT model in Google’s Operations Research (OR) Tools library (OR-Tools, 2022), which has been shown to perform extremely well on a number of different types of combinatorial optimization problems (Perron & Didier, 2020). Constraint programming enables us to more flexibly express constraints and nonlinear objective functions that may otherwise be difficult to encode. While CP-SAT is able to find high-quality solutions to these notoriously difficult geographic rezoning problems, given the size of most districts, it is generally unable to prove that the discovered solutions are optimal. This means that it may be possible to improve upon the reductions in segregation we report, perhaps through additional computational resources and/or alternative model and solver specifications.

The algorithm factors in the following constraints, given they represent topics that are often top of mind for parents and district officials when exploring boundary changes (McMillan, 2018; “Montgomery County Public Schools Districtwide Boundary Analysis,” 2021):

1. **Maximum travel time increases**. We use the OpenRouteService API (GIScience, 2022) to estimate driving times from Census blocks to schools (see more below), and require that re-assignments of blocks to new schools do not increase estimated travel times by more than X% for any given family.

2. **Maximum school size increases**. We use the total population at a given school as a proxy for a quantity parents often care about in their children’s schools—class sizes (Gilraine et al., 2018)—and require that this total does not exceed Y% of its current population.

3. **Contiguity**. Unlike most US states' requirements for Congressional districts ("Congressional Redistricting Criteria and Considerations," 2021), states do not legally mandate school attendance boundaries to be comprised of contiguous geographic units. Still, while they exist in many districts, non-contiguous boundaries are often difficult to justify to families ("Montgomery County Public Schools Districtwide Boundary Analysis," 2021). We define block b to be contiguous with respect to its assigned school s if a line can be drawn on a map from b to the block containing school s without crossing through blocks zoned for any other schools. We enforce contiguity similar to (Mehrotra et al., 1998), with further details available in S1 of the Supplementary Materials. The contiguity constraint requires blocks that are contiguous with respect to their currently-zoned school must remain contiguous with respect to their zoned school under any hypothetical rezoning. Contiguity, of course, is only a proxy for "community cohesion", or a desire for parents to preserve existing geographic and social networks when faced with intra-district boundary changes (Bridges, 2016).

To identify plausible values for X% and Y% above—i.e., the travel time and school size constraints—we use the survey platform Prolific Prolific[1] to conduct a survey of 250 US-based public school parents. We design the survey to better-understand parents' attitudes towards school diversity and the trade-offs they are willing to make to achieve more diverse schools, if any. We gather baseline information about the parents' attitudes towards diversity, as well as information about the child's current school—including current travel times to school and average class sizes. We then ask parents questions like the following: "Let's say that by changing the school zones in your district, an additional [PERCENT] of your child's classmates would come from different [CATEGORY] backgrounds. Imagine this requires traveling further to school. How many more minutes would you be ok with your child traveling to school in order for them to experience this

[1] https://prolific.co/.

increase in diversity?". We randomly select values for [PERCENT] and [CATEGORY] to account for different diversity scenarios (see the Supplementary Materials for additional details). Importantly, we acknowledge the possibility of social desirability bias in parents' responses (Pager & Quillian, 2005) as an important limitation of our survey, and one that may mask several of the underlying racialized preferences for schooling described earlier. In seeking to keep the survey questions simple and relevant to parents, we also acknowledge that our use of "diversity" in them does not directly correspond to the measure of segregation (dissimilarity) that we eventually optimize: how parents and students experience diversity in classrooms is not necessarily well-described by a district-wide measure like dissimilarity.

With these limitations in hand, we find that the median increase in travel times that parents would be willing to accommodate is approximately 60% (or approximately 6 minutes, given the reported median travel time to school 10 minutes), and the median increase in class size is 15% (or approximately 3 students, up from a reported median class size of 22). Based on these values, we set the max travel time increase threshold to be 50% (a conservative lower bound) and the max school size increase to be 15%. We do not accommodate other modes of transport, e.g. requiring students who currently walk to school to be able to continue doing so. This may still occur under our current configurations: e.g., a student's 10 minute walk may translate into a 2 minute drive, which could increase to a max of 3 minutes under our 50% threshold. In the event there is such an alternative nearby option available, and the algorithm reassigns the student to it, it may still be walkable—though not guaranteed to be. Therefore, modeling alternative commute options is an important direction for future work, especially in collaboration with school districts, who may have different transportation options and profiles.

Finally, in general, survey respondents skew more White, affluent, and suburban than national averages, with details on how respondents compare to national averages for US public schools available in S3 of the Supplementary Materials. These representational disparities limit the validity of the survey as a robust indicator of the preferences of families across public education systems in the US. At best, the survey offers us a starting point for grounding our models, but one that must be refined through more participatory, community-centric efforts (a topic we return to in the discussion.)

Figure 1 provides an overview of the problem setup, including the data and parameter inputs into our optimization model (with the input datasets described in more detail below), and our main outcome measures of interests: expected changes in 1) levels of segregation, 2) travel times, and 3) school switching. Section S2 in the Supplementary Materials contains a more detailed description of the optimization model and constraints, including our implementation of the contiguity constraint. Given the computational intensiveness of each rezoning task, we use only one CPU core per rezoning simulation while setting a solver cutoff time of five hours and thirty minutes.

Identifying districts and school attendance boundaries

The most recent school attendance boundary survey conducted by the US Department of Education was in 2015/2016 (Geverdt, 2018). Therefore, for this study, we purchase 2021/2022 school attendance boundaries from the data provider ATTOM[2]. Using 2020 US Census block shape files collected from the US Census website[3], we determine that a block is zoned for a particular elementary school if the centroid of that block falls within the multipolygon delineating the school's attendance zone for 3rd graders. We exclusively use 3rd grade boundaries as our proxy for elementary schools given that 3rd grade is typically classified as an elementary grade, as opposed to e.g. 6th grade, which may be elementary or middle depending on the district/state. In the event a district has overlapping attendance boundaries for certain schools, we map the block to the school with the smallest attendance boundary (in terms of overall area). This occurs for approximately

[2] https://www.attomdata.com/data/boundaries-data/school-attendance-zone-boundaries/.

[3] https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html.

7% of blocks across the districts in our study.

We identify our sample of 98 school districts by applying the following criteria. First, we remove districts that only have one elementary school (and hence, for which the notion of a boundary change is undefined), and those that we do not have 2019/2020 NCES school population counts for (described in the next section). Next, for computational purposes, we include only those districts that have 200 or fewer elementary schools. After applying these filters, we are left with 4,231 school districts in our data. The vast majority—approximately 94% (3,970)—have entirely "closed-enrollment" elementary schools: all of their within-district elementary schools have student assignment defined by attendance boundaries and do not permit attendance by students living outside of those boundaries[4]. Importantly, we note that families across even those districts with all closed-enrollment elementary schools may still opt for out-of-district charter or private options for their children; our datasets do not permit us to know how prevalent this is across particular districts.

The 6% excluded from our sample tend to have a slightly higher White population, slightly higher Hispanic/Latinx population, and slightly higher White/non-White segregation than the remaining 94%. We select the largest 100 districts (in terms of enrollment) across the 94% of districts with closed-enrollment elementary schools. Compared to the other 3,870 districts with no open-enrollment elementary schools, these 100 districts are (by definition) larger, but generally do not have higher levels of White/non-White segregation. Compared to the excluded 6%, these 100 districts are also generally larger, and *do* have a higher level of White/non-White segregation. S4 in the supplementary materials offers further details on these differences. Due to memory limitations in our computing infrastructure, we are able to simulate alternative boundaries for 98 of these 100 districts. These 98 districts constitute our final sample.

[4] These values drop to 88% and 86% when considering middle (7th grade) and high (10th grade) attendance boundaries, suggesting districts are less likely to make choice programs available at younger grade levels.

Estimating students per Census block

We use the 2019/2020 National Center for Education Statistics Common Core of Data[5] to estimate the number of Black, Hispanic/Latinx, White, Native American, and Asian students at each school. In parallel, we download 2020 Census block-level population counts for individuals who are less than 18 years of age and considered to belong to one of the above demographic groups.

With these datasets in hand, we estimate N_{gbs}, i.e. the number of students from group g in block b that attend school s, to be:

$$\frac{C_{gb}}{C_{gB_s}} \cdot s_g \tag{2}$$

Where C_{gb} is the count of individuals belonging to group g and living in block b as estimated from the Census data; C_{gB_s} is the total number of individuals from the Census data belonging to group g across blocks that are zoned for school s (i.e., B_s); and s_g is the total number of students from group g at s. However, in cases where s_g is large, we find that scaling by $\frac{C_{gb}}{C_{gB_s}}$ sometimes leads to counts per block that exceed the total number of students under 18 in that block, as defined by Census data. Therefore, when $\frac{C_{gb}}{C_{gB_s}}$ exceeds 50%, we replace it with $\frac{C_b}{C_{B_s}}$—i.e., we simply assume that the fraction of students belonging to g that attend s from b is proportional to the fraction of total students living in b. Finally, we take the ceil of values and iteratively estimate counts per block (starting with the blocks with the highest value of C_{gb}) until all students at the school have been allocated to a home block. This helps ensure integer student counts, and also, that the total number of students per group across all blocks is equivalent to the number attending the school per the NCES data.

All Census data is collected from (Manson et al., 2021). Our procedures are limited because of our inability to estimate the precise number of students in each block who

[5] https://nces.ed.gov/ccd/files.asp.

attend their zoned elementary school, as some may attend charter, private, or within-district options with open enrollment. Even though certain demographic groups disproportionately may exercise school choice in different settings (Bischoff & Tach, 2020; Rich et al., 2021; Schachner, 2022), because our estimates are based on ground truth school enrollments by demographic group, this differential uptake of school choice is likely to bias our block-level estimates only if families who are part of the same demographic group and assigned to the same school have different rates of school choice uptake that are correlated with the block in which they live. It is not immediately obvious why this might happen, but there are certainly possible explanations (for example, a particular block might house a popular charter or other alternative school option). This could affect the results of our boundary redrawing by either over or understating how much alternative boundaries might impact school diversity. For example, districts with a high fraction of non-White students that have disproportionate numbers of White families opting out of zoned schools in certain blocks compared to others may overstate how much alternative boundaries could increase integration; conversely, higher fractions of non-White families opting out across these blocks (e.g., due to charter options with lotteries that reserve seats for different demographic groups) may understate it.

We acknowledge this important limitation in our estimation procedures, which we believe is addressable through closer collaborations with district partners who are likely to have more precise student counts per block. Section S1 in the Supplementary Materials contains additional details on key assumptions underlying our estimation procedure.

Estimating travel times

We use the OpenRouteService API (GIScience, 2022) to estimate travel (driving) times between block centroids and schools in each district. Given the large number of travel times to compute (millions in some of the larger districts) and the publicly-hosted API's rate limits, we compile and run a local instance of the API on our own server, which enables us to submit an arbitrary number of queries. Queries are comprised of latitude/longitude pairs for a starting location (Census block centroid) and ending location (school location). Travel times do not account for traffic patterns.

Results

We begin by analyzing baseline White/non-White segregation scores for our 98 districts. Figure 2 illustrates the distribution of White/non-White segregation (dissimilarity) scores. The mean and median segregation value across districts is 0.39; the minimum is 0.14; and the maximum is 0.74. Interestingly, this median White/non-White segregation is higher across these districts than median segregation for other demographic groups (Asian/non-Asian, Black/non-Black, Hispanic/Latinx/ non-Hispanic/Latinx, Native American/non-Native American), suggesting that this dimension of segregation is still particularly salient across many US school districts.

The current segregation scores suggest there is room for improvement under alternative boundary scenarios. But how much improvement might we expect? Implementing the optimization procedure described earlier yields Figure 3, which illustrates changes in segregation values, school assignments, and travel times produced by our models across districts (error bars depict 95% bias-corrected and accelerated confidence intervals, computed using the boot library in R (Canty & Ripley, 2021; Davison & Hinkley, 1997)). From 3(a), we see that if each district in our sample adopted the boundary changes produced by our models, median White/non-White segregation across districts could shift from 0.39 to 0.33. When computing the pairwise before/after reductions per district, this translates to a median absolute decrease of approximately 0.04—corresponding to a median 12% relative decrease in segregation across districts. Figure 3(b) illustrates these changes at the district level. Conducting exploratory correlational analyses, we observe no statistically-significant association between absolute decreases in segregation and urbanicity ($ANOVA\ F = 0.66, p = 0.58$) or district size ($Spearman\ \rho = .06, p = .53$), and a weak relationship with initial levels of segregation ($Spearman\ \rho = -0.17, p = 0.09$). *These results suggest that the unique geographic and demographic contexts of different districts are likely to determine how much intra-district attendance boundary changes can increase school diversity more than overarching characteristics like district size, current levels of segregation, or urbanicity.*

Figures 3(c)-(e) illustrate the costs of achieving these reductions in segregation. From (c), we see that reducing White/non-White segregation would not lead to higher segregation levels for other racial groups (i.e., Black/non-Black; Hispanic/Latinx non-Hispanic/Latinx; etc). In fact, the other racial groups would also experience reductions in segregation under the depicted rezonings. In (d), we see that, on average, approximately 20% of students from different groups would be required to switch schools, and that the burden of school switching could be distributed approximately evenly across student groups. While 20% represents a relatively large fraction of students, it is less than the nearly 40% of parents in our survey who expressed a willingness to switch schools if their district redrew attendance boundaries. From an implementation perspective, districts may also phase boundary changes in gradually instead of all at once, reducing the number of students required to switch schools in any given year. The literature on the impact of school switching on student academic and subjective well being outcomes is mixed, with some findings illustrating positive benefits conditional on switching to attend better schools, and others illustrating adverse consequences (Hanushek et al., 2004; Schwartz et al., 2017). Weighing the potential disruption costs of school switching alongside the potential gains of more integrated schools is important when determining when and how to make boundary changes.

Somewhat surprisingly, plot (e) shows that average school switcher would actually experience a *decrease* in their travel times to and from school, despite the fact that our model permitted up to a 50% increase in travel times for any given family. This is notable because it suggests that 1) long-range "busing" (Delmont, 2016) is not necessarily required to achieve more diversity in schools, and 2) some existing attendance boundaries may potentially be drawn ("gerrymandered") in ways that assign students to schools further from their homes, resulting in slightly higher levels of segregation as a result (Richards, 2014). We note the speculative nature of this latter point, especially given the existence of research suggesting that irregulary-shaped boundaries may actually contribute to *greater* integration (Saporito & Riper, 2016). Indeed, it is possible families may have moved after the implementation of such boundaries precisely to avoid more integrated schools, producing a net increase in segregation. Further research is needed to better understand precisely why it appears that current boundaries could be redrawn to foster integration while also reducing travel times. Finally, an important observation from Figures 3(c)-(e) is that, again on average across districts, the potential costs of desegregation are fairly distributed across the depicted racial and ethnic groups.

A median 12% relative decrease in segregation across districts represents a non-trivial step towards more integrated schools, yet it is also far from achieving full integration, illustrating how the choices of constraint values impact how much progress districts might make towards integration. For example, setting the max travel increase threshold to 100% (or in the most extreme case, allowing families to experience a doubling in travel time to school) could yield a median relative decrease in segregation of 16%, but would require nearly 30% of students to switch schools and experience a slight average increase in travel times of approximately half a minute to school. Keeping the travel time increase at a maximum of 50% but dropping the contiguity constraint could yield a median relative decrease in segregation of 40%, but would require approximately 45% of students to switch schools, and a 1.5 minute average increase in travel to school. Applying both of these relaxations together—not requiring contiguity and allowing larger increases in travel times—could decrease segregation by nearly two-thirds (6̃5%) and effectively eliminate segregation in 15 of our 98 districts, but would also require two-thirds of students to switch schools, and an average increase of nearly 4 minutes spent traveling to school. Section S4 in the Supplementary Materials includes additional details on these sensitivity analyses.

Importantly, our analyses do not factor in the likelihood of complex system dynamics that could manifest if districts actually *did* adopt the rezonings described here—for example, neighborhood relocation ("white flight") (Reber, 2005) in response to unfavorable rezonings, or the disproportionate use of school choice by families—namely, those who are more privileged—to opt for other district or charter options that enable them to circumvent the effects of changing boundaries. While we've attempted to solicit parent input to model boundary changes that parents are more likely to accept, these preferences offer only a limited starting point. Furthermore, it is impossible to know how parents will actually respond to any particular rezoning if proposed and eventually implemented in practice. Incorporating likely reactions and decisions among families into our models based on historical responses to boundary changes, and/or direct input from districts and parents about their views on the viability of particular rezonings, are therefore important avenues for future work.

While we report averages across districts in Figure 3, these averages potentially mask heterogeneities across different types of districts. To explore some of these heterogeneities, we conduct two case studies. The first involves the most segregated district in our sample, Atlanta Public Schools, which has a segregation score of 0.74 and serves nearly 23,000 students across 44 closed-enrollment attendance boundary elementary schools. The second involves the district closest to the median level of segregation across districts in our sample: Mesa Unified District, Arizona, which has a segregation score 0.39 and serves nearly 31,000 students across 52 closed-enrollment elementary schools.

Figures 4 and 5 illustrate the outputs of these case studies. Maps (a)-(c) in each figure illustrate the present-day elementary school attendance boundaries, the relative prevalence of White students per Census block, and our hypothetical rezoning. Examining (d) illustrates how the fraction of students in the depicted group would change at each school after implementing the alternative zoning, compared to before. As expected, rezonings generally move school-level demographics to reflect district-level proportions as much as possible, sometimes shifting the percentage of White students at a given school by several fold, as seen in Figure 4(d). The most substantial changes also appear to occur within a small subset of schools, with most schools across the district experiencing little or no change. However, some schools become more segregated with respect to the district: that is, a subset of schools which already have a proportion of White or non-White students exceeding district-level proportions see an increase in their White or non-White share, respectively, and therefore diverge further from, instead of converging to, district-level shares of White/non-White students. These fluctuations are more extreme in Atlanta compared to Mesa Unified, and to be expected given our dissimilarity objective function, which optimizes an aggregate district-level measure without explicitly requiring that reductions in segregation be evenly redistributed across individual schools.

Minimizing the maximum term in the summation depicted in equation 1 to reflect a "leximin" objective function based on the Rawlsian Difference Principle (Hooker, 2014) may help alleviate some of these issues, as might imposing constraints that explicitly disallow schools with demographic proportions that already deviate from district proportions to deviate further. However, these alternative formulations are also likely to produce smaller reductions in district-wide segregation. Changing the objective function altogether may also impact results, though we find that optimizing for a different measure of segregation—a modified "interaction index" similar to the one proposed in (Massey & Denton, 1988)—yields results similar to those generated by seeking to minimize district-wide dissimilarity. Section S4 in the Supplementary Materials includes additional details on these objective function sensitivity checks. In practice, the choice of objective function, overall desegregation goals (including specific schools of focus), and even notions of fairness are likely to be context-specific and require input and domain expertise from both districts leaders and families.

Plots (e) through (g) in each case study depict the changes in segregation, school assignments, and travel times expected across demographic groups. In both cases, we see slight reductions in segregation and travel times across demographic groups, with the exception of Native American students in the Mesa Unified case, who would experience a slight average increase of 0.5 minutes in travel each way. Furthermore, in Figure 5(f) (Mesa Unified), we see a relatively balanced school switching requirement across demographic groups; however, in the corresponding plot for Atlanta (Figure 4(f)), we see large disparities across groups. Most notably, White students are nearly 3x as likely as Black students to have to switch schools, and rates of school switching for Asian, Hispanic/Latinx, and Native American students also near 30% or higher, though the number of students falling into these latter three demographic groups in Atlanta are small. These differences show that even though in an aggregate sense across districts, school switching is fairly distributed across groups, these results will likely vary by district. This highlights both several of the trade-offs district officials might need to make in order to achieve more integrated schools, but also opportunities for more creative approaches to modeling, constraining, and ultimately addressing the issue of changing policies in order to mitigate segregation.

Discussion

Our results demonstrate that there are practical and fair pathways to changing attendance boundaries in order to achieve more diverse schools, though the impact these policies have on individual schools and different student groups—for example, who would be required to switch schools, and how much school switching might either further or hinder these students' academic progress—can vary across districts. This reality calls for a nuanced and district-specific approach to modeling, evaluating, and eventually adopting potential boundary changes. Particularly notable is that there exist alternative boundary scenarios that might reduce segregation *and travel times* across districts, highlighting that these are not always at odds, and contrasting with the public narrative around long-range busing that emerged among many majority-race members of the population during desegregation efforts in the 20th century (Delmont, 2016).

While we observe a relative decrease of 12% in the median segregation score across districts, these improvements are largely a function of the constraints our models impose, and still constitute only small steps towards addressing issues of White/non-White segregation. Nevertheless, as our sensitivity analyses show, changing constraint values can have a multiplier effect on how much alternative boundaries might reduce segregation. To support explorations of these sensitivities and the impact different policies might have on individual schools and demographic groups, we release a public dashboard[6] and its underlying code and data illustrating different boundary scenarios and outcomes for the districts we explore in this study. We invite researchers to use these resources to explore new models that capture more of the nuances and specifics individual districts often consider when making boundary changes (some of which we discuss below). We also invite districts and families to explore the outputs in the dashboard and comment on their viability as starting points for informing realistic policies for fostering more diverse schools.

Parents' racialized preferences for where they live and send their children to school will continue to act as formidable headwinds challenging even the most thoughtful and well-designed efforts to foster more diverse schools. Our study does not contribute to answering the normative question of how to change these preferences, or the political one of whether school districts can garner the will to implement policies that improve integration. However, it offers an empirical contribution that we believe may be of interest to both researchers and school districts: that such improvements appear to be possible across many districts, and that they can be achieved with practical and fair tradeoffs. Even then, which tradeoffs count as "practical" and "fair" will differ across communities and individuals, and across racial/ethnic and class lines. This points to a number of limitations in our current study, which in turn open the door to new and exciting directions for future work. We classify these limitations as opportunities across three interconnected categories

[6] www.schooldiversity.org.

that we invite researchers and interested practitioners to explore in greater detail: data, model, and broader relevance to education policy efforts.

With respect to data, our method relies on estimated counts of students per group, per Census block. As described further in Materials and Methods and the Supplementary Materials (section S1), this requires making certain assumptions about how the population of each school is distributed across blocks—notably, without a sense of how frequently school choice (e.g., charter or private school selection) is exercised by different demographic groups across these blocks. We are also unable to factor in other data, like transportation costs, that districts might weigh as they decide on rezoning policies. The limited window that Free/Reduced-priced lunch provides into students' socioeconomic status (Harwell & LeBeau, 2010), coupled with the limited availability of family socioeconomic indicators at the Census block level, prevents us from exploring other dimensions of segregation that districts value and often prioritize targeting (Potter, 2016). Working closely with specific district partners to obtain and incorporate more detailed, historical, and up-to-date data may help alleviate many of these issues. Finally, we proxy "community cohesion" with contiguity. In reality, a family's community, and students' friends, are a function of geography along with many other (potentially unobservable) factors. Developing more nuanced ways of determining and factoring in notions of community into rezoning models may open the door to new boundary configurations that promote diversity while satisfying family and district-level preferences.

There are also a number of model improvements that may make our results more useful in practice. Optimizing for different measures of segregation, ranging from simple extensions to the dissimilarity measure (like imposing an L2 loss instead of the current L1) to exploring alternative segregation measures altogether is an important future direction, especially given many of the limitations of the dissimilarity index that we discussed earlier. Balancing utilization across schools, limiting the percentage of students who are rezoned (a la ("Montgomery County Public Schools Districtwide Boundary Analysis," 2021)), and even more explicitly factoring in fairness requirements instead of merely analyzing fairness post hoc also offer promising directions for model refinements. To ensure increases in elementary school diversity also propagate to middle and high schools, exploring objective functions that factor in feeder patterns and account for the full K12 lifecycle—instead of only the earlier years—may also produce more practical and desirable boundary changes. As mentioned earlier, we may also expand our model to incorporate historical data or domain expertise to predict how a given rezoning might spark families to leave neighborhoods ("white flight") and/or disproportionately leverage school choice to access other district or charter options that enable them to circumvent unfavorable reassignments—and factor these possibilities into the optimization process. Finally, given that diversity may not today be a core consideration or impetus for redrawing boundaries in most districts, we might augment our models to aid district policymakers in simulating new boundaries when exploring questions more germane to their day-to-day, like determining locations for new schools, or deciding which schools to shut down (for example, in response to declining enrollment). With minor extensions, the models we present here can aid with these decisions while still foregrounding their potential impacts on diversity, travel, and other outcomes of interest.

Perhaps the biggest open question from our study is: how might families and district leaders respond to these hypothetical rezonings, and how much could they actually increase diversity in schools? We believe this is an important avenue for follow-on research, and a critical part of translating this research into education policies that help promote school diversity. In reality, district school assignment policies are often a function of attendance boundaries, but also, opportunities for transferring or switching schools when families find boundary assignments unfavorable; new boundaries that are phased in over time, instead of all at once; "open-enrollment" charter and magnet programs; "zones of choice" that define meta-boundaries for clusters of schools that parents can then choose amongst (Allman et al., 2021; Campos & Kearns, 2022); and several other policies, many of which are emergent. Furthermore, as discussed in the introduction, most segregation in schools can be attributed to boundary delineations *between* districts, not simply those within them. While attendance boundaries play a foundational role in school assignment policies across most districts, expanding our methodology to account for nuances pertaining to school choice, and more generally, expanding geographic scope to explore between-district boundary changes (a more challenging computational problem as well) may help yield policy simulations that produce more practical and effective pathways to integrated schools. Capturing and factoring in input from both families and district leaders, for example, through participatory (Kensing & Blomberg, 1998) and value sensitive (Friedman et al., 2013) design methods may further help inform school desegregation policies that are realistic and practically-achievable.

Changing school demographics does not guarantee more diverse friendships, sharing of social capital and resources, greater empathy for different life experiences, and other potential gains that can ultimately benefit all students (Chetty et al., 2022; Moody, 2001; Tatum, 1997). Yet it is a necessary first step towards achieving many of these downstream outcomes. We hope this study is a useful building block to support future work on this critical topic.

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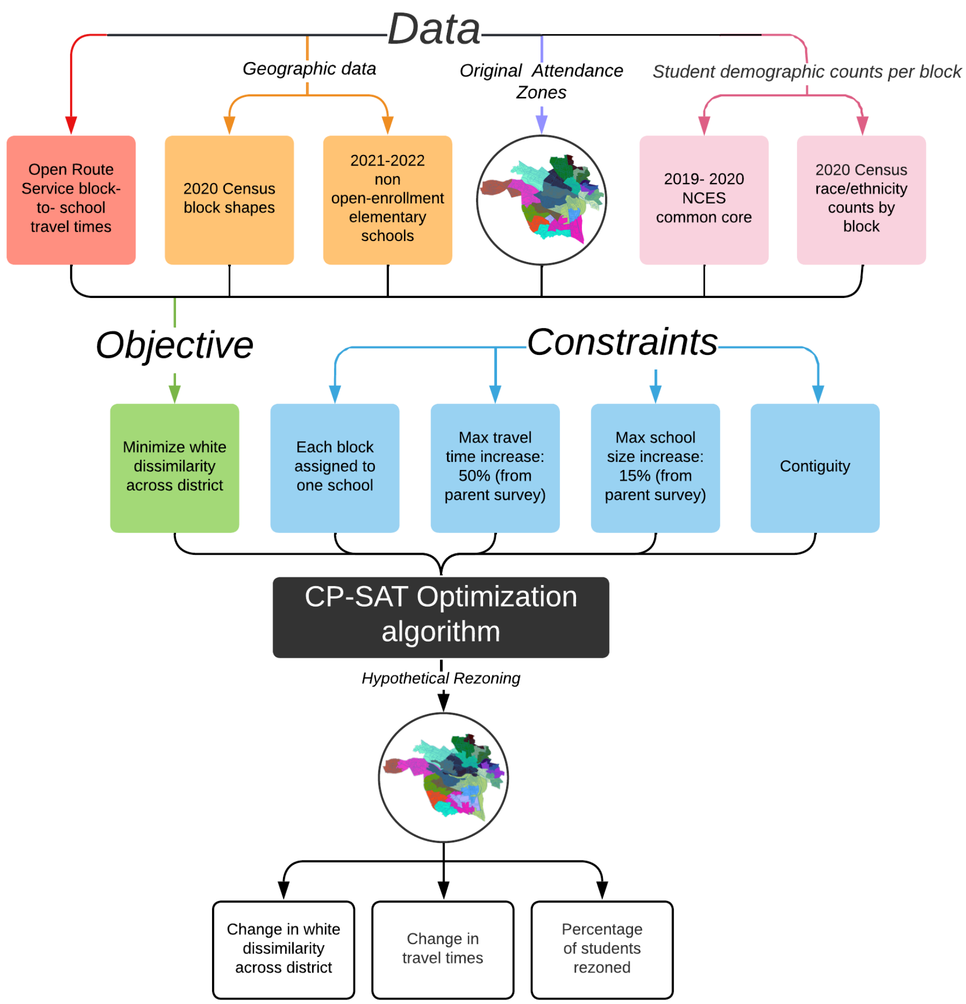

Figure 1

Input data, objective function, constraints, and outcome measures from our optimization model.

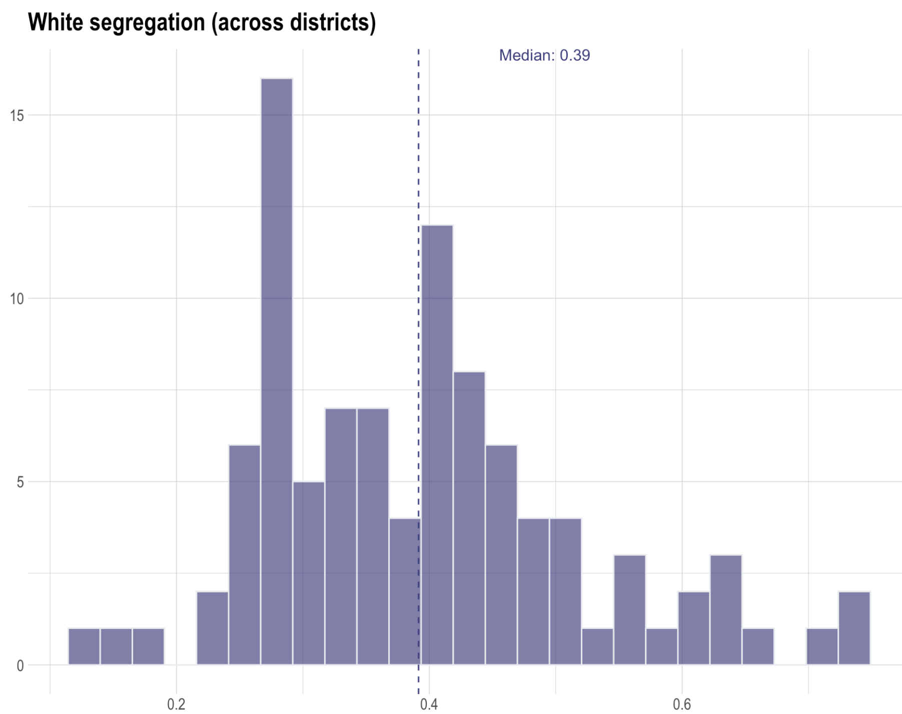

Figure 2

Histogram of dissimilarity indices across the 98 districts in our sample.

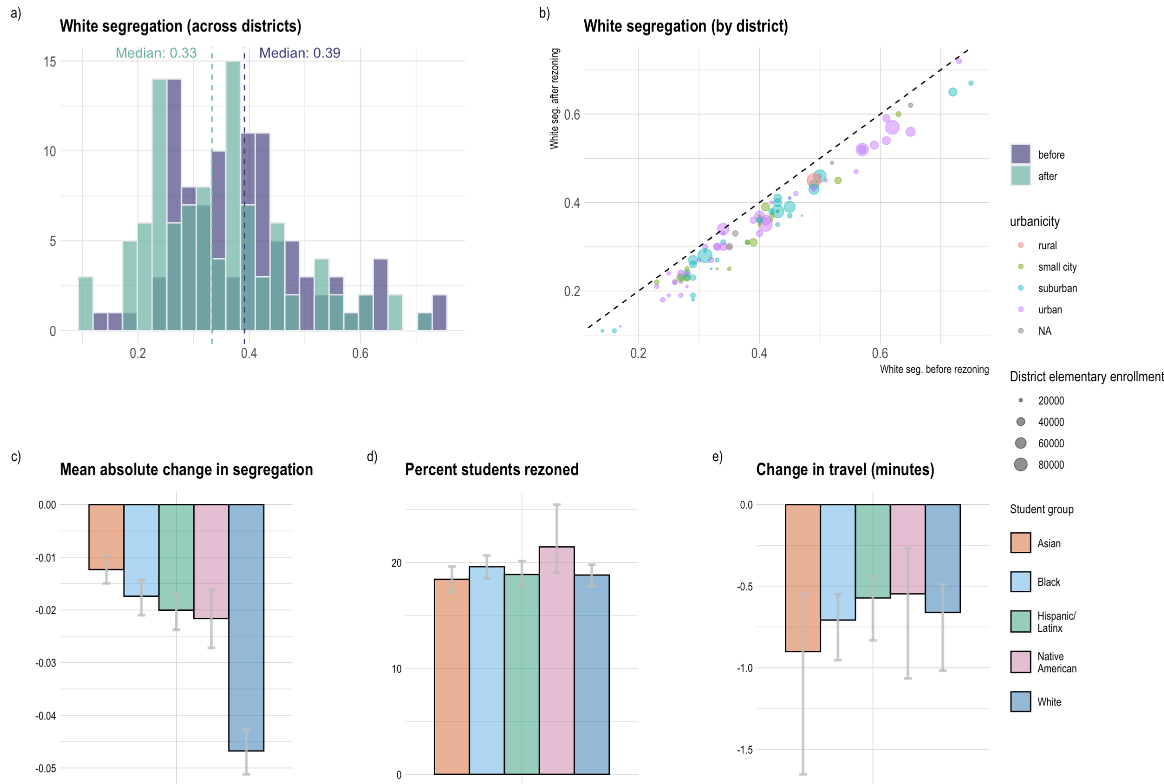

Figure 3

Results from our rezoning algorithm. ***a)*** *shows a shift in the median of the distribution of segregation scores from 0.39 to 0.33 across districts, which corresponds to a median 12% relative decrease when computing pairwise changes per district.* ***b)*** *illustrates these pairwise changes; interestingly, there is no relationship between the size or urbanicity of a district and the reduction in segregation that it experiences, and a weak relationship between the amount of reduction and the original segregation score.* ***c)*** *shows that segregation scores for all racial/ethnic groups decrease, albeit marginally, under the proposed rezonings.* ***d)*** *illustrates that, on average across districts, school switching under the depicted rezonings are relatively evenly distributed across racial and ethnic groups. Finally,* ***e)*** *illustrates that the depicted boundary changes might actually decrease average travel times across school districts and demographic groups. Together, these findings show that there are pathways to more integrated schools across districts that may not require large sacrifices by families.*

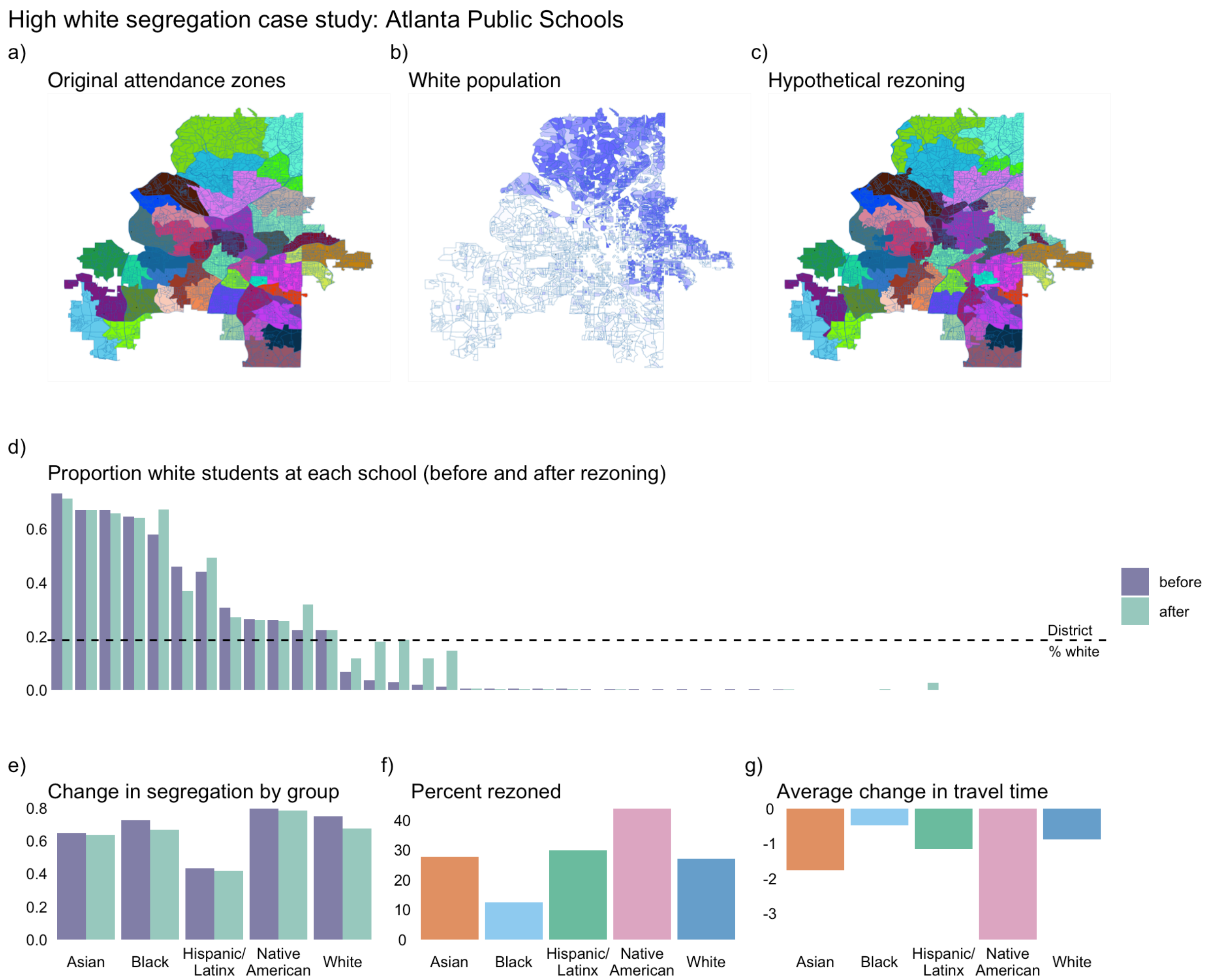

Figure 4

*Case study for the most White/non-White segregated district in our sample, Atlanta Public Schools, which has a segregation score of 0.74. The shapes in **a)** through **c)** represent 2020 US census blocks; the colors in **a)** delineate 2021/2022 school attendance boundaries for the depicted district ("status quo"); **b)** shows the estimated percent of each block's population estimated to be white (darker blue implies a higher percentage), with blocks removed if they are estimated to have a student population of zero. **c)** shows the rezoning produced by our algorithm. **d)** shows the expected change in the proportion of students at each elementary school in the district who are White, before and after rezoning. **e)** through **g)** show the anticipated changes in segregation scores, percentage of students needing to be rezoned, and change in travel times for each demographic group. The results reveal several notable findings. First, as expected, the most dramatic boundary changes appear to occur in school boundaries that fall at the interface of White and non-White parts of the city. Additionally, as shown in **d)**, changes in school-level distributions tend towards the district White student percentage, which makes sense given our objective function, with a handful of schools experiencing the most dramatic changes. However, the share of White students is also increased at several schools that already have a White share higher than the district, illustrating trade-offs district leaders may be faced with when deciding which schools to target with desegregation efforts. From **e)** and **g)**, we see that all student groups would experience reductions in segregation and travel times, respectively, but **f)** shows disparities in which students might be rezoned—with the largest fraction found among Native American (7 out of 16), Hispanic/Latinx (524 out of 1,756), and Asian (93 out of 336) students.*

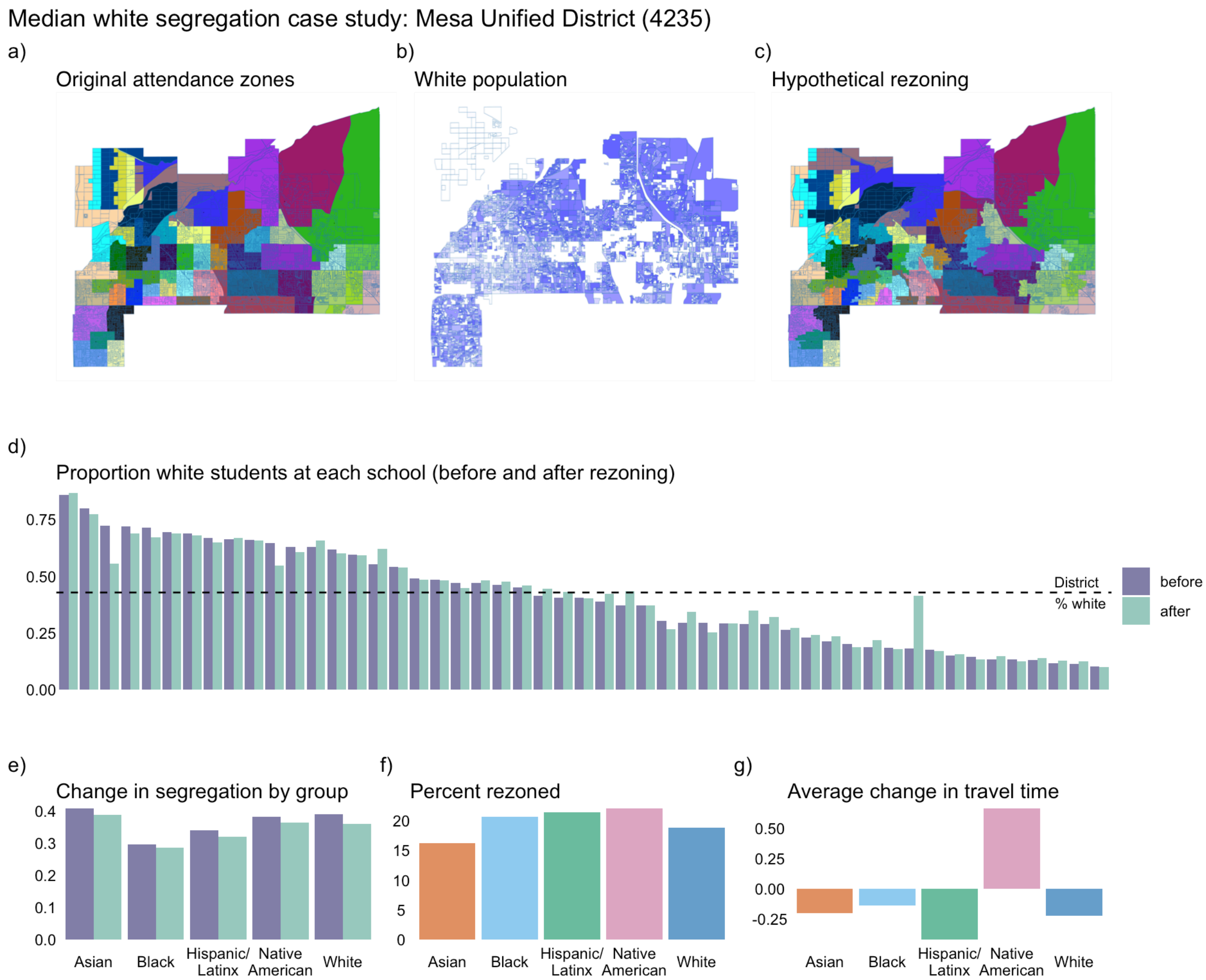

Figure 5

Case study for a typical (median) White/non-White segregated district in our sample, Mesa Unified, which has a segregation score of 0.39. Plots ***a)-g)*** *defined analogously to Figure 4. In general, we observe similar trends as the Atlanta case study, with fewer disparities in the percentage of students across demographic groups who would be rezoned, and a marginal increase in travel times for the 270 out of 1,220 Native American students in the district who would be rezoned.*

Supplementary Materials for "Redrawing attendance boundaries to promote racial and ethnic diversity in elementary schools"

Contents

S1 Datasets and assumptions

In the main text, we describe the datasets we use in the study. Perhaps the most central quantity we estimate using these datasets is the number of students per group that feed to each school from each correspondingly-zoned Census block. We describe our estimation procedure for this quantity in the Methods and Materials section of the main text. Estimating this, however, requires making a number of assumptions (in addition to those described in the main text), which we detail here:

1. Assumption: Non open-enrollment schools draw students from each group proportional to the demographics of the blocks that fall in its attendance boundary. As described in the main text, even though certain demographic groups disproportionately may exercise school choice in different settings (3, 14, 15), because our estimates are based on ground truth school enrollments by demographic group, this differential uptake of school choice is likely to bias our block-level estimates only if families who are part of the same demographic group and assigned to the same school have different rates of school choice uptake that are correlated with the block in which they live. This may happen for a variety of reasons, e.g. if a particular block houses a popular charter or other alternative school option, and hence, may bias our block-level estimates and subsequent impact of rezoning on school diversity in either direction (see the main text for examples of how).

2. Assumption: All datasets are drawn from the same year. In reality, our school-level demographics data is drawn from the 2019/2020 National Center for Education Statistics' Common Core of Data; our Census block delineations and counts from the most recent 2020 census; and attendance boundary data reflecting 2021/2022 school year boundaries. We use the 2019/2020 NCES data as our base set of schools, including only those for which we have lat/long information[1].

3. Assumption: When estimating the number of White, Black, and Hispanic/Latinx students per block, that the percentage of people under 18 years of age living in the corresponding block and belonging to each of these categories is proportional to the percentage of students who attend a given zoned elementary school from that block.

4. Assumption: The 2020 Census block-level values represent accurate counts of children under 18 years of age belonging to each demographic group. In reality, these estimates have noise applied to them for privacy preservation reasons and therefore may be biased in ways that could impact downstream applications, like redistricting procedures (8).

We believe these are reasonable assumptions given the datasets we have access to. However, as described in the main text, we acknowledge that an important avenue for future work is to obtain more up-to-date and accurate block-level student counts (e.g., through close collaborations with individual districts) to produce a more nuanced and precise view of how alternative attendance boundaries might affect chances for diverse exposures in elementary schools. This is particularly important if we wish to support actual policy-making with this work.

S2 Optimization model

We define a binary matrix for each district d, $X_d^{|B|\times|S|}$, where B is the set of census blocks and S the set of schools in the district, respectively. Our key decision variables are the entries of this matrix, i.e. each x_{bs}, which equals 1 if block b is assigned to school s, or 0 otherwise.

As described in the main text, our primary objective is to maximize:

[1] Which we sourced through a separate data agreement with GreatSchools.org, since lat/longs for the 2019/2020 schools database were not yet available in the NCES dataset at the time of completing this study.

$$\frac{1}{2}\ \Sigma_{sS}\ |\frac{W_s}{W_T} - \frac{NW_s}{NW_T}| \tag{S1}$$

Our constraints are defined as follows. First, we require that blocks are assigned to exactly one school, i.e.:

$$\forall_{b \in B}\ \Sigma_{s \in S}\ x_{bs} = 1 \tag{S2}$$

Next, we require that travel times do not exceed some fraction T longer than they currently are:

$$\forall_{b \in B}\ \Sigma_{s \in S}\ x_{bs} \cdot travel_{bs} \leq (1 + T) \cdot travel_{bs^{orig}} \tag{S3}$$

Where *travel* is a pre-computed matrix (using the Open Route Service API (4)) with dimensionality $|B| \times |S|$ that denotes estimated driving times between each block centroid and district elementary school, and s^{orig} is the school b is zoned to in the original ("status quo") zoning.

Next, we require that school populations do not exceed a P% increase:

$$\forall_{s \in S}\ \Sigma_{b \in B}\ x_{bs} \cdot N_b \leq (1 + P) \cdot s_{origpop} \tag{S4}$$

Where $s_{origpop}$ is the status quo population size of school s.

Finally, we impose contiguity constraints. As described in (5), contiguity is often a challenging requirement to impose in redistricting problems because doing so exactly requires an exponential number of constraints. Thus, like (5), we use an approach presented in (10), which defines a limited but still valid notion of contiguity where the blocks comprising each attendance boundary must constitute a subtree (network) of the shortest path tree rooted at the block containing the zoned school. For a block to be considered contiguous with respect to its zoned school, there must be at least one other adjacent block in this tree that is closer (in network distance) to the school that is also zoned to that school. We use breadth first search to build out these tree (network) representations for each school's status quo boundary. Our contiguity constraint requires that blocks satisfying this definition of contiguity in the original zoning must continue to do so in any rezoning, or more formally:

$$\forall_{b \in B}\ Contiguous(b, s_{before}) = 1 => \ Contiguous(b, s_{after}) \tag{S5}$$

Where s_{before} and s_{after} are the before and after school assignments for each block b, and the function $Contiguous(b, s)$ is defined as:

$$assert(x_{bs} = 1 => \ \Sigma_{b' \in B_b^{closerneighbors}}\ x_{b's} > 0) \tag{S6}$$

Where $B_b^{closerneighbors}$ is the set of b's neighboring blocks that are closer than it (in terms of network distance) to school s. Under this formulation, blocks that are islands—i.e., not contiguous in the original zoning—can continue to remain islands in any rezoning. Importantly, enforcing contiguity does not ensure resulting boundaries that are "nicely-shaped": often, our model satisfies the above constraint by chaining together blocks that are only adjacent by virtue of sharing a corner or some other limited geographic region, thereby producing oblong or otherwise oddly-shaped zones that would likely be difficult to defend in practice among parents and district leaders. To increase the likelihood of well-shaped attendance zones, we additionally require that a minimum of G% of block b's same-school-zoned neighboring blocks in the original zoning (i.e., $B_b^{neighbors} \subset B$) continue to be zoned with it even after rezoning, i.e.:

$$\forall_{b \in B} \forall_{s \in S}\ x_{bs} = 1 => \ \Sigma_{b' \in B_b^{neighbors}}\ x_{b's} \geq ceil(G \cdot |B_b^{neighbors}|) \tag{S7}$$

We set G to 50%, but future work may explore how changing this parameter changes resultant rezonings and impacts on segregation.

In practice, even with the contiguity constraint imposed, districts may have algorithmically-generated boundaries that appear non-contiguous due to one of the following reasons (which occur infrequently):

1. A block that was an island in the original zoning has been re-assigned to a school that previously had a completely contiguous zone
2. Due to geographic precision issues, blocks that are adjacent to other blocks are not recognized as such in the shape file, and hence counted as islands
3. Two blocks may technically be adjacent because their boundaries are touching, even though they may not visually appear to be, perhaps because of long boundary lines in the shape file and/or the presence of intermediary blocks with imperceptibly thin geographic areas that serve to join the two

To search for alternative boundary scenarios, we use constraint programming via Google's CP-SAT library (11). CP-SAT uses a hybrid set of search heuristics to uncover high-quality solutions to operations research problems like the one highlighted here, drawing upon recent advances like lazy clause generation (13, 16) and other methods for pruning large search spaces based on constraint and objective function values. Despite the successes of CP-SAT, developing bespoke search algorithms that exploit the specific nature and structure of our problem may serve as a promising avenue for future work.

S3 Parent survey

We administer a survey on Prolific.co[2], an online survey platform for academic and market researchers. We set a budget of $500 to collect 250 responses from eligible families: those who have at least one child in a public preK-12 program in the US. This totals approximately $2 per survey, or $1.50 paid out to each survey respondent after accounting for platform fees (translating to an average of approximately $20/hour given the relatively short average completion time per survey). Given the benign and anonymous nature of the intervention, we receive IRB exemption for this human subjects study.

To reach these families on the platform, we applied a filter on Prolific to only show the survey to potential respondents who live in the US and have at least one child born between 2005 and 2015 (inclusive). Even though our study focuses on elementary schools, we target parents of children across this wide age band to increase the likelihood of gathering our targeted number of responses[3].

Upon visiting the survey, Prolific workers are first asked to confirm that they have at least one child in a public preK-12 program in the US. Those who answer "no" are directed to the end of

[2] https://www.prolific.co/.

[3] While Prolific has 150k+ total participants, only 3k were estimated to fit the filtering criteria we established.

the survey and not counted towards the total respondent count[4].

Next, eligible respondents see a variety of questions that ask them to comment on the importance of diversity in their child's schooling. Figures S1 and S2 shows responses to these questions. In general, a large majority of parents state that they believe it is important for their children to be exposed to a racially/culturally, economically, and intellectually diverse group of students—reflecting preferences for more integration in schools revealed by prior surveys (e.g. (17)). Furthermore, most cite a variety of benefits they see of diverse exposures: the most popular being that such exposures can help their children develop more compassion and empathy for others, and the least popular being that such exposures can help their children be more creative in problem solving (Figure S2).

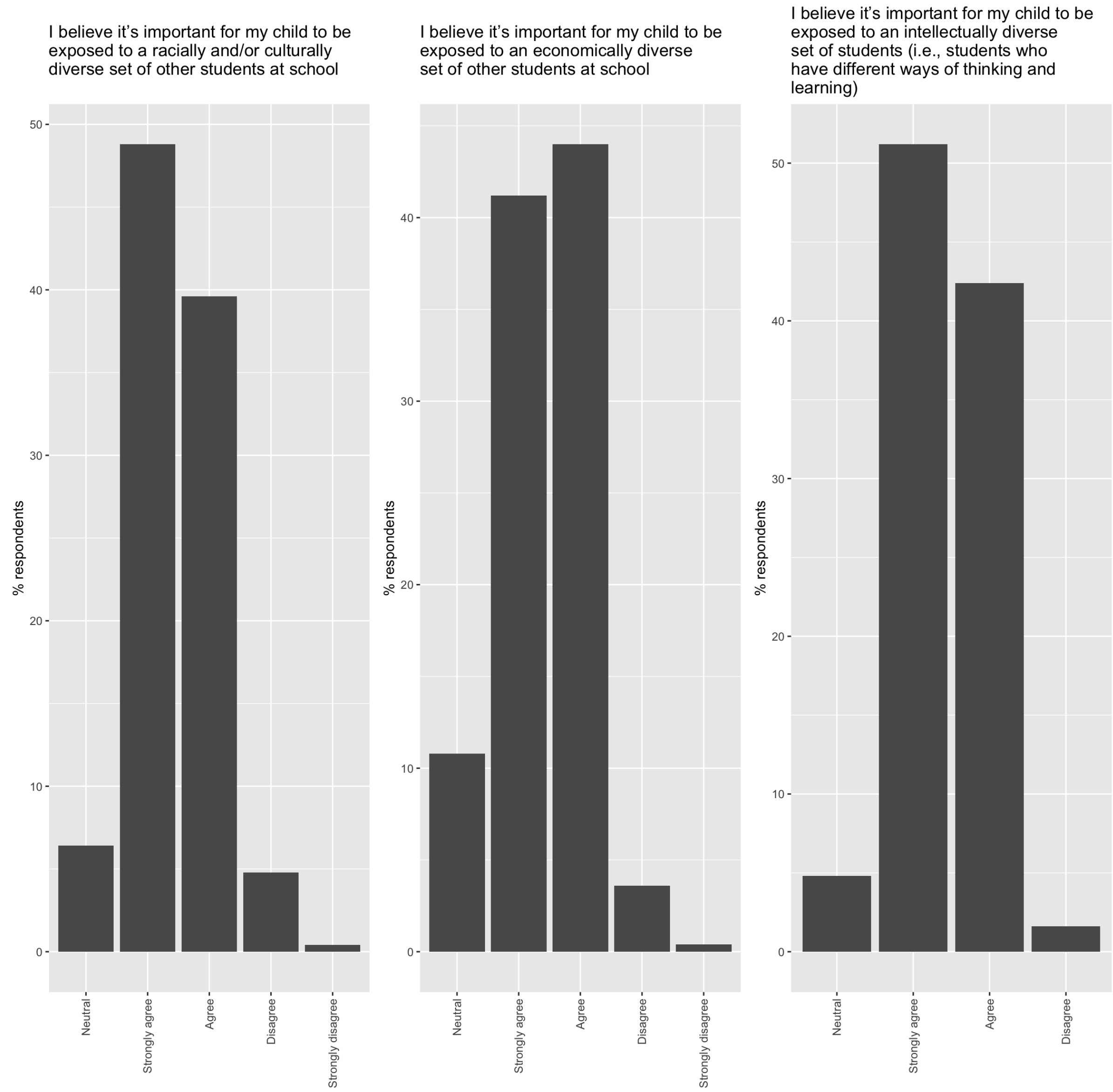

Figure S1: Parents' stated beliefs about the benefits of diverse exposures for their children.

Next, to gather baseline information to inform our optimization algorithm constraints, we ask parents to share information about logistics pertaining to their child's current school and neigh-

[4]Looking at some of our results, however, shows that a small handful of parents (5) with children in private schools still completed the survey.

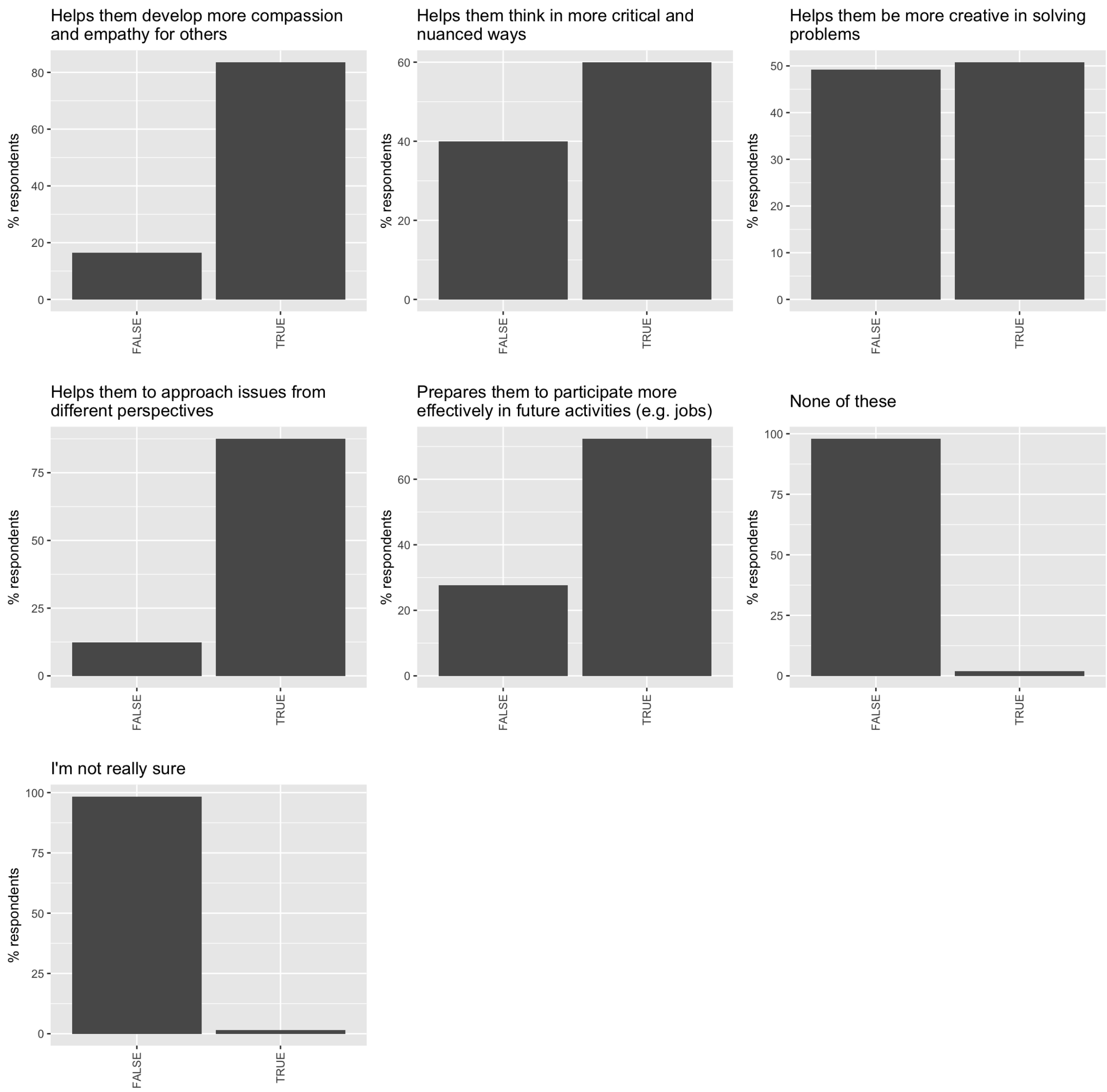

Figure S2: Parents' beliefs about *why* diversity is important in their children's schooling.

borhood environments. Figure S3 shows that the respondents' children's median class size is approximately 22 students and median travel time to school is 10 minutes. Furthermore, most students travel by car or bus to school. To better-understand relationships between geography and children's friendship networks, we ask "Which of the following groups does your child hang out / spend time with regularly?", with results shown in Figure S4. The majority of respondents indicate that their children's friends live nearby, but not necessarily on their street, and just under 50% indicate they live in other neighborhoods. A minority indicate they live next door or on the same street as them. These responses indicate that geography is correlated with children's friendship networks, but immediate geographic contexts may not be as correlated as broader definitions of "neighborhoods".

Unrelated to logistics but related to the overall goals of our study, we ask parents to what extent they believe they can partner with teachers and administrators to improve lower-performing schools. The purposes of this question is to better-understand how malleable parents' view school quality to be, given that school quality has historically been a popular consideration among

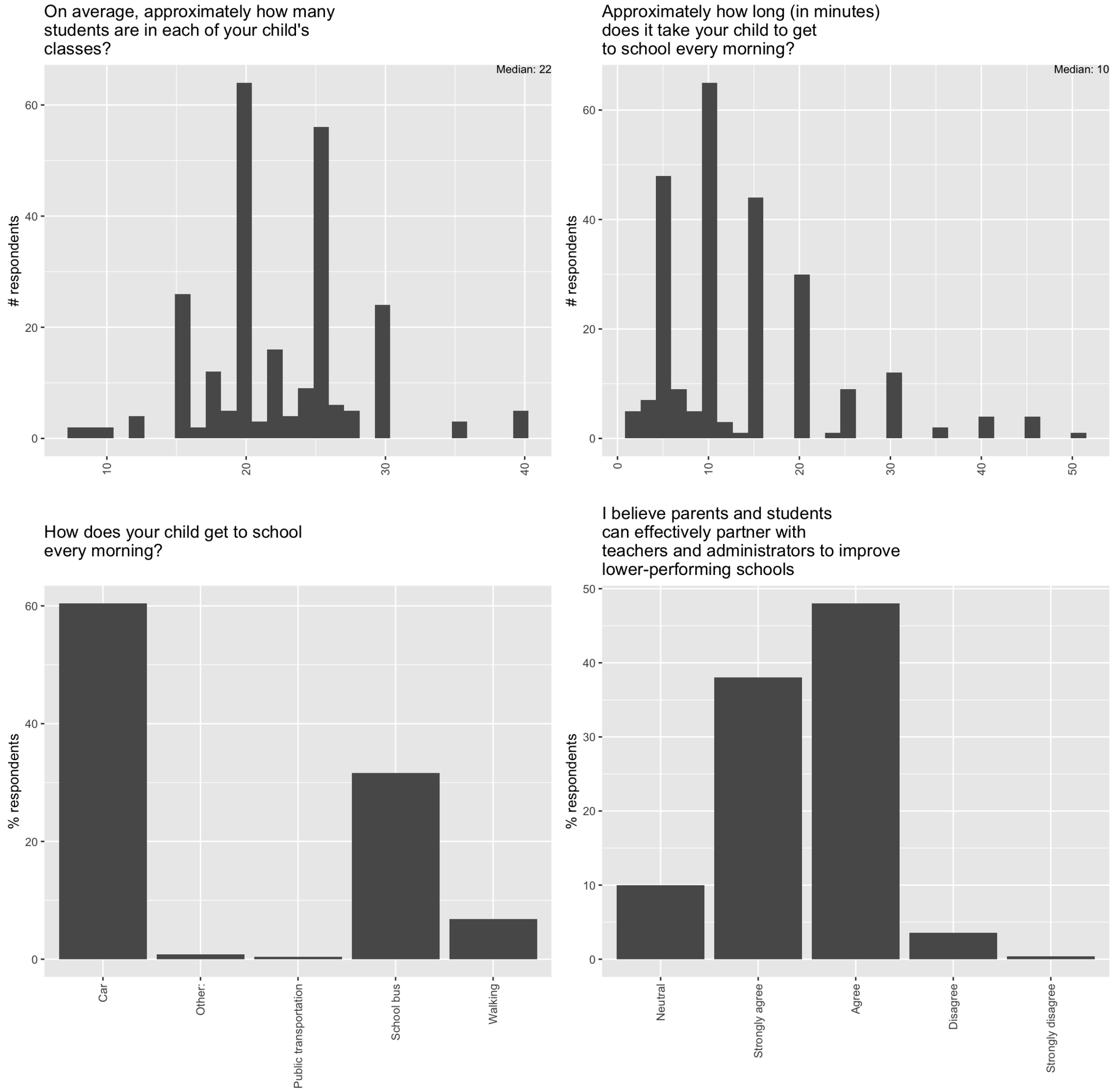

Figure S3: Responses to school-related logistics questions. The final question does not necessarily pertain to logistics; rather, parents' views about the malleability of school quality, which is often an important consideration among parents when attendance boundaries change. Perhaps surprisingly, parents appear to believe that it is possible to partner with school leaders to change school quality for lower-performing schools.

parents in the context of attendance boundary changes and broader desegregation programs (19). Perhaps surprisingly, we find that the vast majority of parents believe school quality is malleable, and that lower-performing schools can be improved through effective partnerships with key school leaders.

After these preliminary questions, we move onto the main part of the survey. Parents see the following questions and are asked to indicate their responses using a slider. We randomly and independently sample values for DIVERSITY_PERCENT (from {10%, 25%}) and DIVERSITY_CATEGORY (from {'racial or ethnic', 'income', 'academic achievement'}).

> Let's say that by changing the school zones in your district, an additional DIVERSITY_PERCENT of your child's classmates would come from different DIVERSITY_CATEGORY backgrounds.

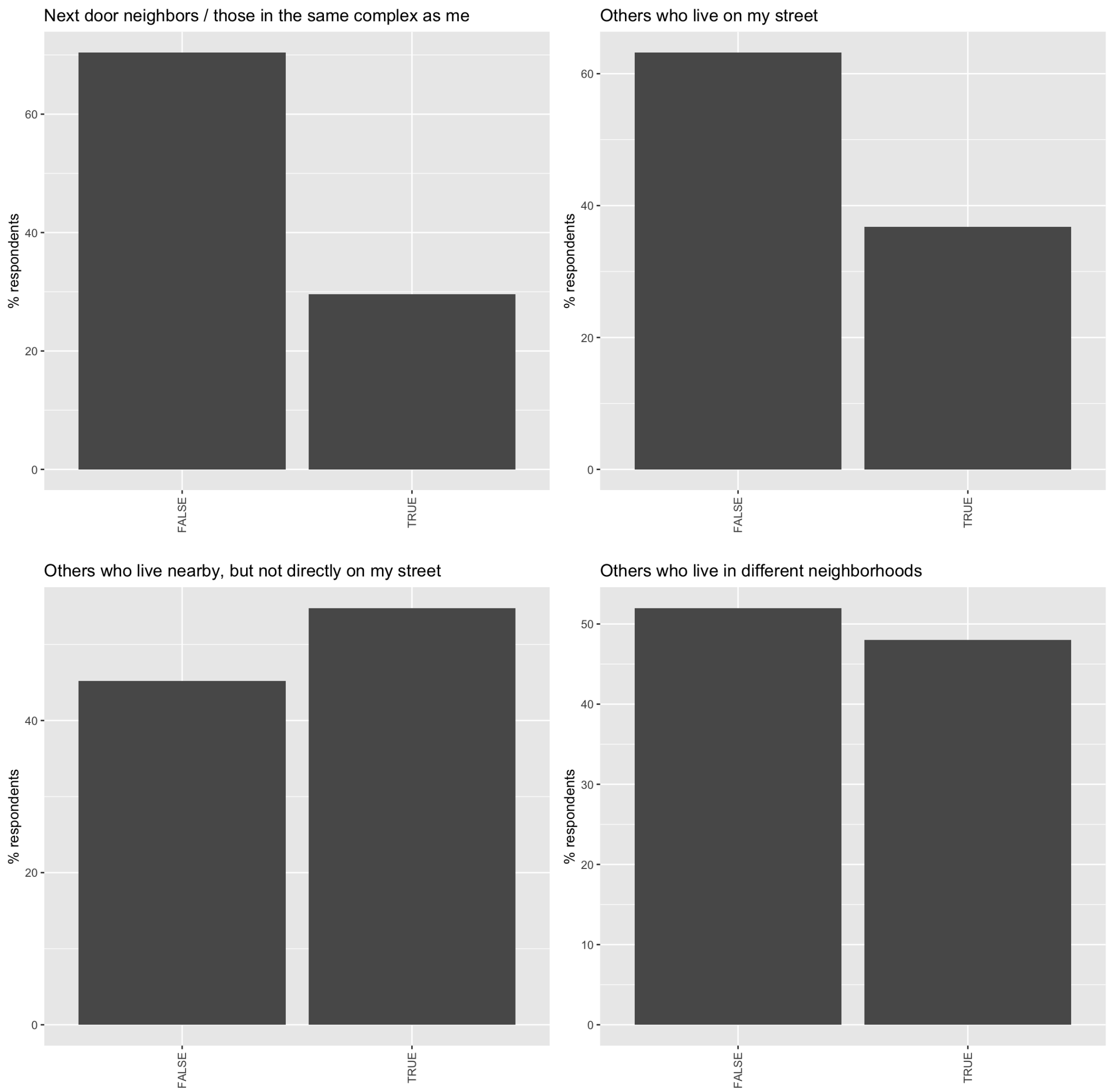

Figure S4: Responses to questions probing which groups respondents' children usually hang out / spend time with regularly.

> Imagine this requires traveling further to school. How many more minutes would you be ok with your child traveling to school in order for them to experience this increase in diversity?
>
> Let's say that by changing the school zones in your district, an additional DIVERSITY_PERCENT of your child's classmates would come from different DIVERSITY_CATEGORY backgrounds. Imagine this requires increasing your child's average class size. How many more students per class would you be ok with in order for your child to experience this increase in diversity?
>
> Let's say that by changing the school zones in your district, an additional DIVERSITY_PERCENT of your child's classmates would come from different DIVERSITY_CATEGORY backgrounds. Imagine this requires some of the families in your neighborhood being rezoned to schools different from your child's. What is the largest % of these families that you would be ok with being rezoned to a different school?

In addition to these questions, we also ask parents to respond with "yes", "no", or "it depends" to the following question: “Let’s say that the school zones in your district were changed, and your child now had to attend a different school. Would you send your child to this new school?”

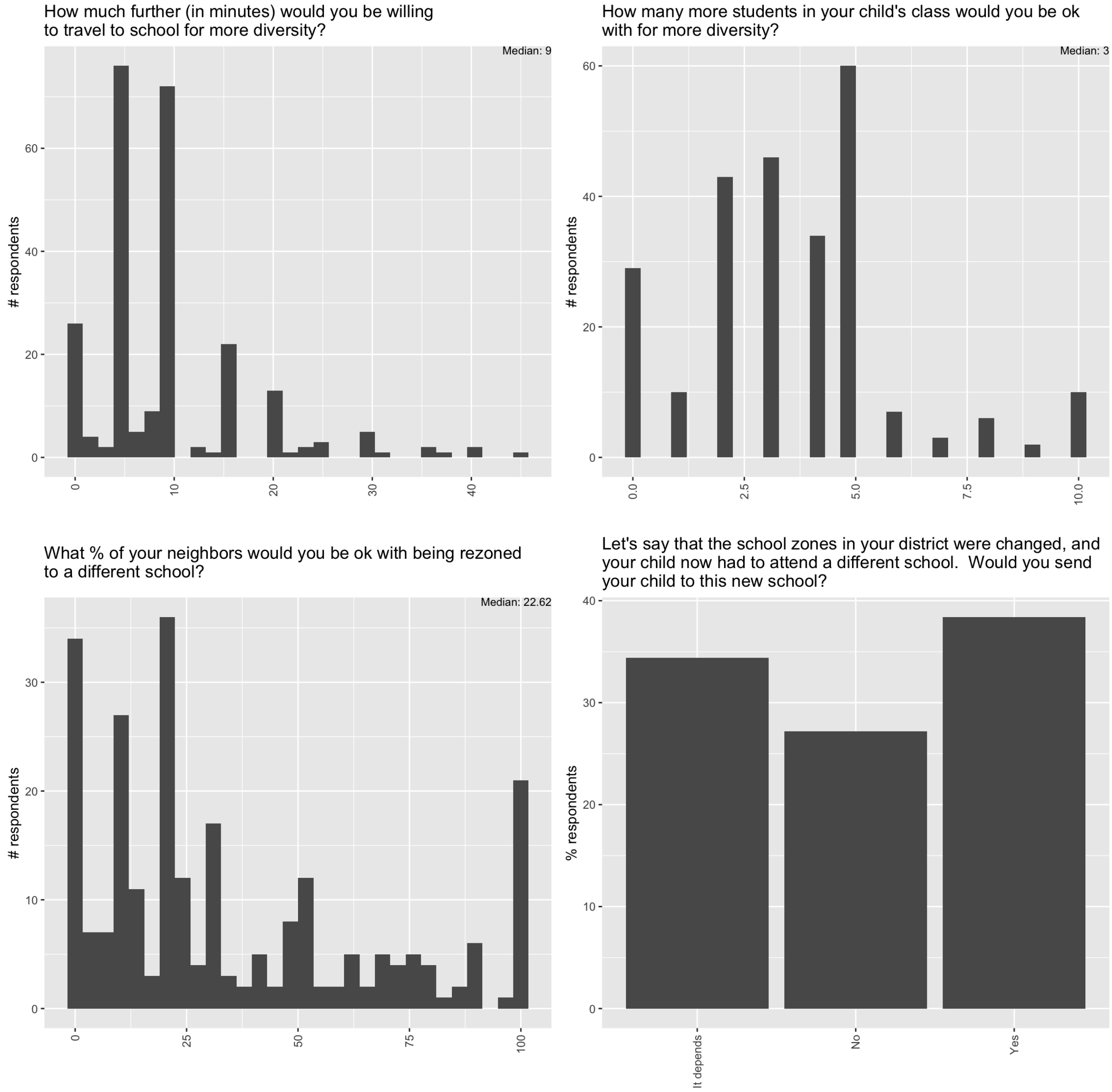

Figure S5: Responses to questions probing which groups respondents’ children usually hang out / spend time with regularly.

Figure S5 shows responses to these questions, and Figure S6 illustrates the responses to the first two questions as a ratio of students’ current travel times and class sizes as gleaned from the preliminary survey questions. We find that parents are willing to experience a median of 67% longer commute times and 15% larger class sizes for their children in order to achieve more diverse classroom environments for their children. Furthermore, families are willing to tolerate nearly one quarter (23%) of families in their neighborhoods being rezoned to different schools in order to experience these gains in diversity. While the travel time increase tolerance threshold appears to be large, it translates into an increase of approximately 6-7 minutes, given baseline travel times are already low. The 15% larger class size tolerance threshold translates into approximately 3 additional students per class. We use both of these values to inform the travel time and school size constraints in our “best case scenario” optimizations described in the main text.

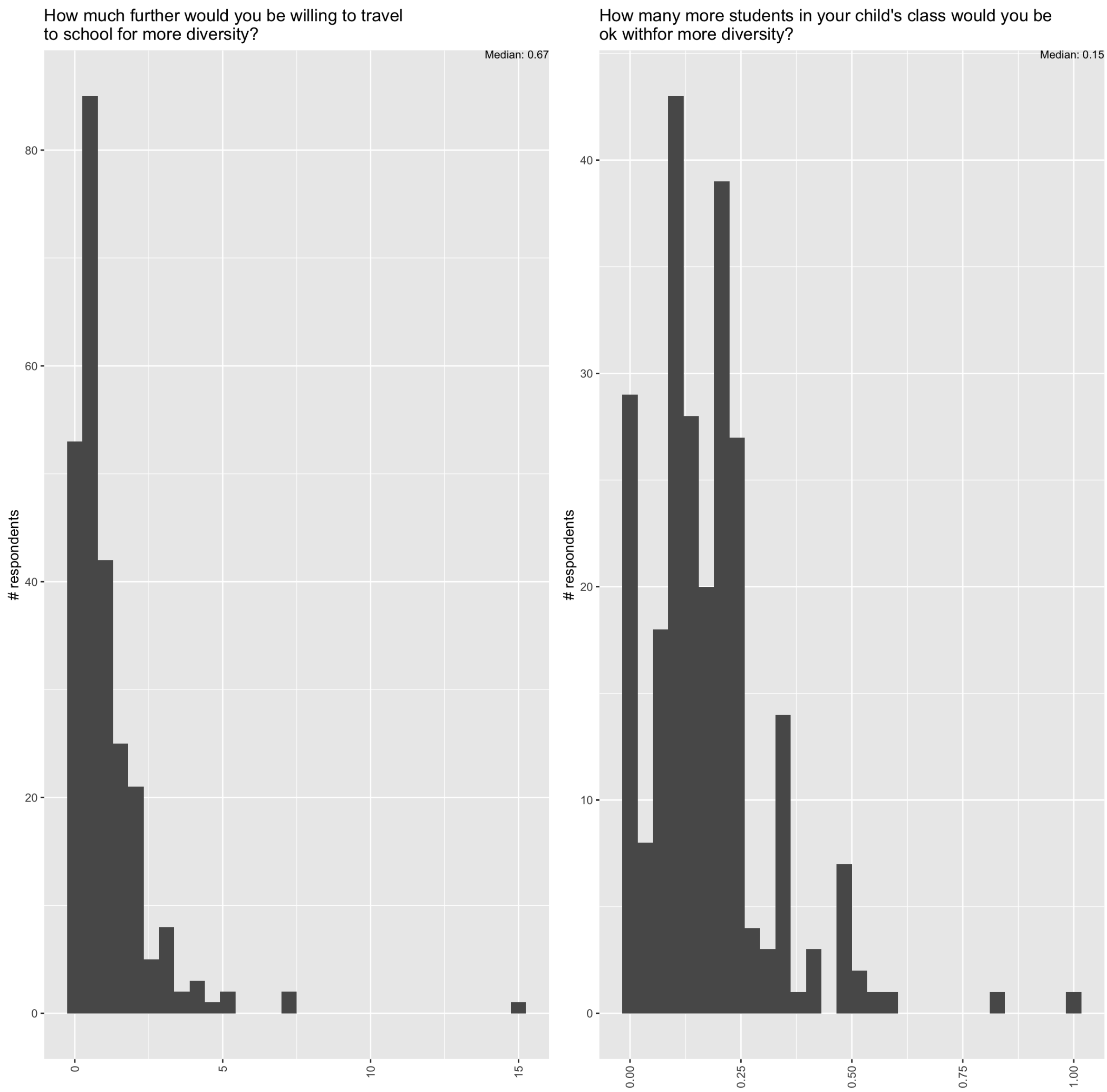

Figure S6: Ratio of parents' travel time and class size increase responses compared to preliminary survey question responses about their children's current travel times and class sizes, respectively.

In general, the survey responses reveal that parents are not willing to trade-off a lot for more diversity in their children's classrooms. However, they do appear to be willing to trade-off *something*, suggesting there may be near-term opportunities for promoting integration in schools that are currently under-explored.

We note that because we randomly-assigned both DIVERSITY_PERCENT and DIVERSITY_CATEGORY, the results described above can be interpreted as responses to changes in diversity averaged across the potential values for these variables. To understand heterogeneities that may be masked by these averages, we can analyze the causal effect of each of these variables on parents' responses. Figure S7 illustrates the outputs of models that regress responses to each of the four questions on these two experimental variables (we use OLS for the first three questions given the outcome variables are continuous, and logistic regression for the fourth, where we collapse responses to "yes" (1) or "not yes" (0)). We treat DIVERSITY_PERCENT as a continuous variable and set the reference category for the discrete DIVERSITY_CATEGORY variable is "racial or ethnic".

Interestingly, we see no statistically significant effects of any of the variables on outcomes, though cannot rule out that a larger sample size or differently-worded questions may reveal significant causal effects in potential future studies.

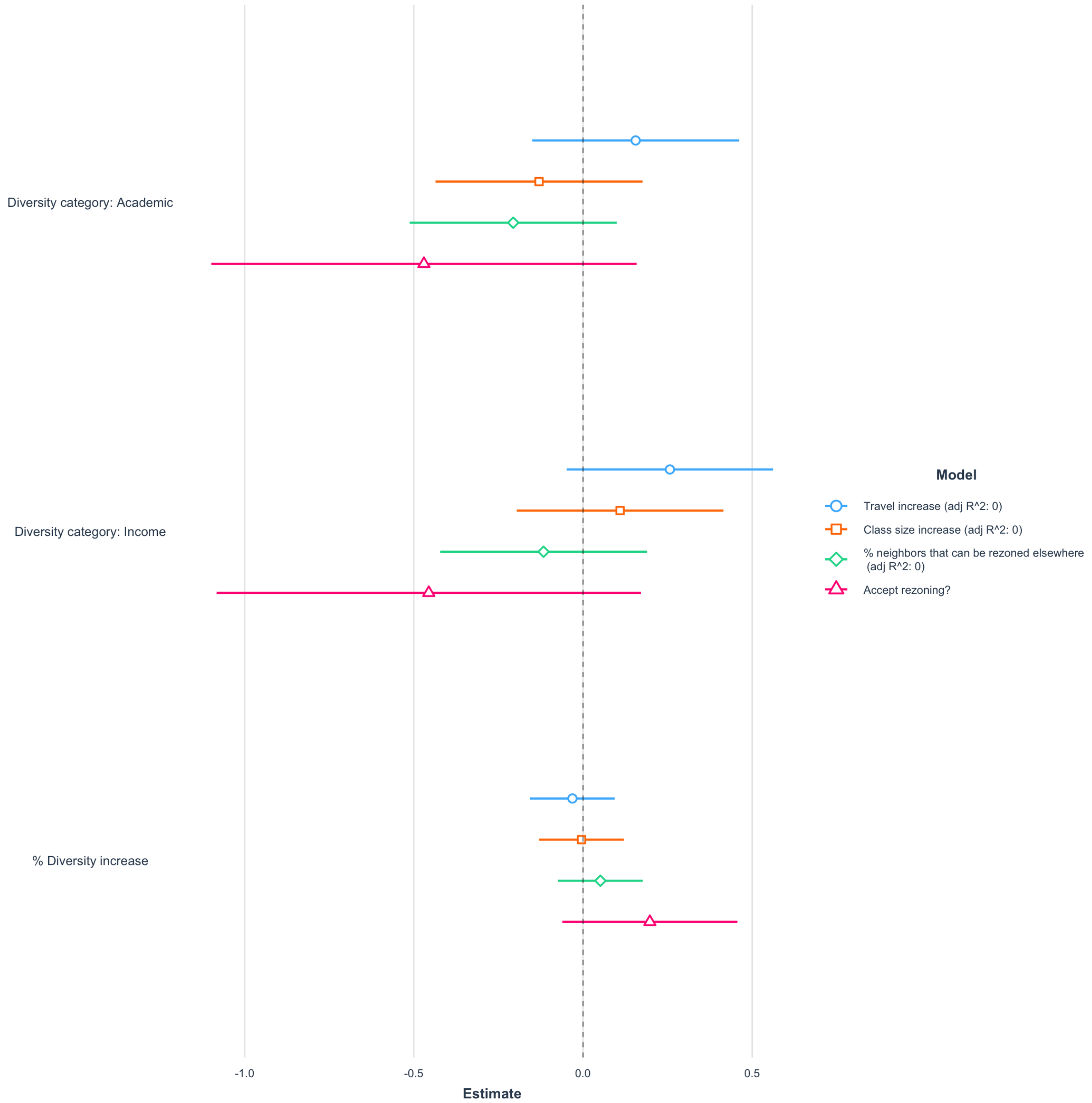

Figure S7: Causal effects of experimental variables on our four outcomes of interest. Lines depict 95% confidence intervals. Interestingly, we see no statistically-significant effects of either variable on our outcome measures.

The results to the fourth question—"Let's say that the school zones in your district were changed, and your child now had to attend a different school. Would you send your child to this new school?"—reveals a relatively low number of parents answering with a hard "no" (less than 30%). An approximately equivalent fraction respond with "yes" and "it depends". Those who respond with the latter are asked to share more information to contextualize their response. Below are the open-ended responses shared for this question, with distinct responses separated by "***". Many parents answering this question appear to consider quality of the new school, as well as distance, as important factors in deciding whether or not they would accept a hypothetical rezoning.

```
"Our school is very close and we really love it. I would need MAJOR incentive to
    switch so it would depend on the school and what other benefit aside from added
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diversity***It would depend on how far the school was and what I thought of the teachers and student ratio at the school.***I would want them to go to a school in the district in which I live.***We are already in a different district due to the quality of the schools in our district. So, it would really depend on the quality of the school.***Depends on how far away it is, how many friends they have there, how good the school is, etc***Depends on the character and reputation of the school***It depends on the area and the school system, I value good schools that promote learning with students.***It would depend on the quality of the other school.***It depends on the level of academics in the school, the safety factor of the school, and the distance of the school. ***I chose this neighborhood for the school system. If I had to change I'd have to consider the entirety of the situation including classroom size, teacher qualifications, parents involvement, safety, etc.***It depends on the administration and rating of the school***On the gifted offerings at the new school ***It depends on how high of quality the education is at this new school as well as how many of my child's friends were also sent to this school .***What the classes sizes were. The socio-economics of that area.***I would need to know how good the school is and how far away it is. ***Would depend on how well the school is doing.***It depends on the status of the school. If it is bad, i'm not putting my child in a position to be hurt.***It would depend on the makeup of the school, the opportunities that were offered there, and how balanced the school is.***It would depend on how my daughter feels about it*** it depends how it will impact the travel time***It depends on how far away the school is and in what area it's located.***My child's school is already so close that the next closest school would be about 20 minutes away.***Need more information, how would they get there, etc***If the new school had better resources for my daughter and would help her academically I would consider it. ***Depends on how far the other school is.***If the school is better performing I would consider it. I would also consider it if the commute time to the school is not too much longer.***Depends on how far of commute it is and how good the school is***which school will fit his needs better***How close and if the school is still as good ***the quality of the new school facilities and the distance from home and how many of their friends would be moving or already there***It all comes down to how far it is and of course, how good the school is.***they go to a private school***I don't know enough about the other schools outside my zoning district, I would want to learn about them first before making this decision.***It depends on where trey want us to go.we all ready have school of choice.***It depends on how far the school is, what area it is located in, and the curriculum and how dedicated the curriculum is to children of my daughter's demographic background***It depends on the test scores of the school. ***I would consider private/homeschooling if the school was not up to our standards***I would need further information about the school and it's situation to decide***It depends on the curriculum of the school and the school 's overall reputation. ***He loves his current school, depends on what the other is like.***It depends on if the school is ran the same way their current one is and how far away it is***I have 3 children. Realistically we wouldn't be able to achieve diversity in our area without dramatically adding to our travel time. Even though I believe diversity is important we just don't have the ability to add 40-60 minutes transit time each day to achieve it, nor can we afford to move. In our area, rezoning wouldn't create more diversity, and would just be uprooting them to a school with new kids but similar racial makeup. It would likely be more of a disruption than actual benefit. At some point, I will return to the work force, so I cannot count on being able to drive kids to and from school everyday. Therefore, we need to stay at our local school.***If the academic quality is lower, then no.***It depend son the quality of education all round***Depends if if has great teachers***If there were no other schools then I would swnd him***We currently send our child to an out of district school for before and after care reasons. If 5he new school was better and our schedule would allow the change, we would consider it.. *** What if it is a terrible school?***on the distance and quality of the school*** CASE BY CASE BASIS. I WOULD NEVER GO A INCH OUT OF MY WAY FOR DIVERSITY ETC.... I AM NOT CONCERNED WITH OTHERS ONLY MYSELF AND MY CHILD.***It would have to be a reasonable distance away and a place that I felt safe sending my child to.*** we have open enrollment here, so it would depend on the school staff***My son's school is great. There is a lot of diversity and the administration and staff really care for all of the kids. It would be very to find another school like his.***We chose to live where we live based on the schools the neighborhood feeds into. If the school changed enough to where I didn't feel it was a good fit for my kids, I would change schools.***it depends on how far and my child's transportation options***Is school safe and have high education standards *** Would depend on options for private schools ***n/a***It would depend on which school, and how good the school itself is***i would not want my child to be a minority there. I would want an equal mix of majority and minority***if I was forced to or not. ***It would depend on the quality of education they would receive.***On the quality of the school and educators***It depends on how the school is run.***Depends on how far it is. I like having my child walk to school everyday.***It depends on the condition of the school, the reviews and the distance of the school.***My child is very, very shy and does not do well without a friend. I would be pretty upset if she didn't have at least one friend in the new classes with her. We've had her in therapy because of this. ***He has autism, it would depend on the teacher and how well they would follow his IEP***I wouldn[U+FFFD][U+FFFD][U+FFFD]t want him to be on the bus for a long time each way***what school it was going to be***While I would like my child to be exposed to more diversity, whether I would send him to a rezoned school depends primarily on the academic profile of the school and whether the school can meet my son's academic needs. ***How far would it be. How many student's on avg per class. Do they need police officers at school. ***It depends on what the changes would be***I would research crime rates.***My child currently goes to a private school.***How far is the school? How are the academics? What is the school community like? The other parents? The further away, the more complicated it is to do everything from commute to play dates, etc. ***If possible I would see if he could be dropped off and picked up because we are in a really good school district. He enjoys his school so i would like to keep him there if possiblet***there are two districts in out zone and it depends which one she would be sent to***on the environment and academics of the new school***I would need more info first. Is the quality of education the same?***I would need my child's opinion on the issue. Their social life is very important to them and thriving for the first time in awhile .***If he would be comfortable changing then I would be ok with it. ***I would need to understand what the new school was like***It depends on what/where the school is.***This actually happened to us and I opted to keep my son in the same school, but it was his last year in elementary school and I wanted him to experience the year with his friends he had for years. If it had been an earlier year, I might have just let him move to the new school. They were both racially similar so diversity was not a factor. The new school would have had more of my son's race probably, but he loved his old elementary so I asked to keep him there one more year. (And, it was closer.) ***It depends on the location***I'm fine with zoning that makes classrooms more diverse but I think that the closest school and the number of students per class is a more important factor.***How far away, type fo school, etc***It would depend on distance, benefits, and school performance."

Finally, we conclude the survey with a number of questions to better-understand respondents and their background contexts. Figure S8 shows the racial background of respondents' children. The vast majority are White (over 80%), which is significantly higher than the 50% estimated across all US public school districts (1). Furthermore, Black and Hispanic/Latinx respondents are under-represented in the data compared to national percentages across public schools, while Asian respondents are over-represented (1). Students eligible for free and reduced-price lunch are also under-represented in our survey data (40%) compared to national averages (50%)[5]. These trends may be due in part to the large fraction of respondents hailing from suburban districts as shown in Figure S9, which have historically skewed whiter and more affluent, though this is changing in many communities (18). Also evident from Figure S9 is that, on average, families believe their child is above average in academic performance, reflecting parents' upwardly-biased beliefs about children's performance found in other studies (2). Finally, a plurality of respondents (40%) self-identify as Democrats, with the remaining approximately equally-likely to identify as Independents or Republicans. Respondents appear to exhibit average levels of "affective political polarization, i.e., feelings of hostility or animosity against political "outgroups" (7)

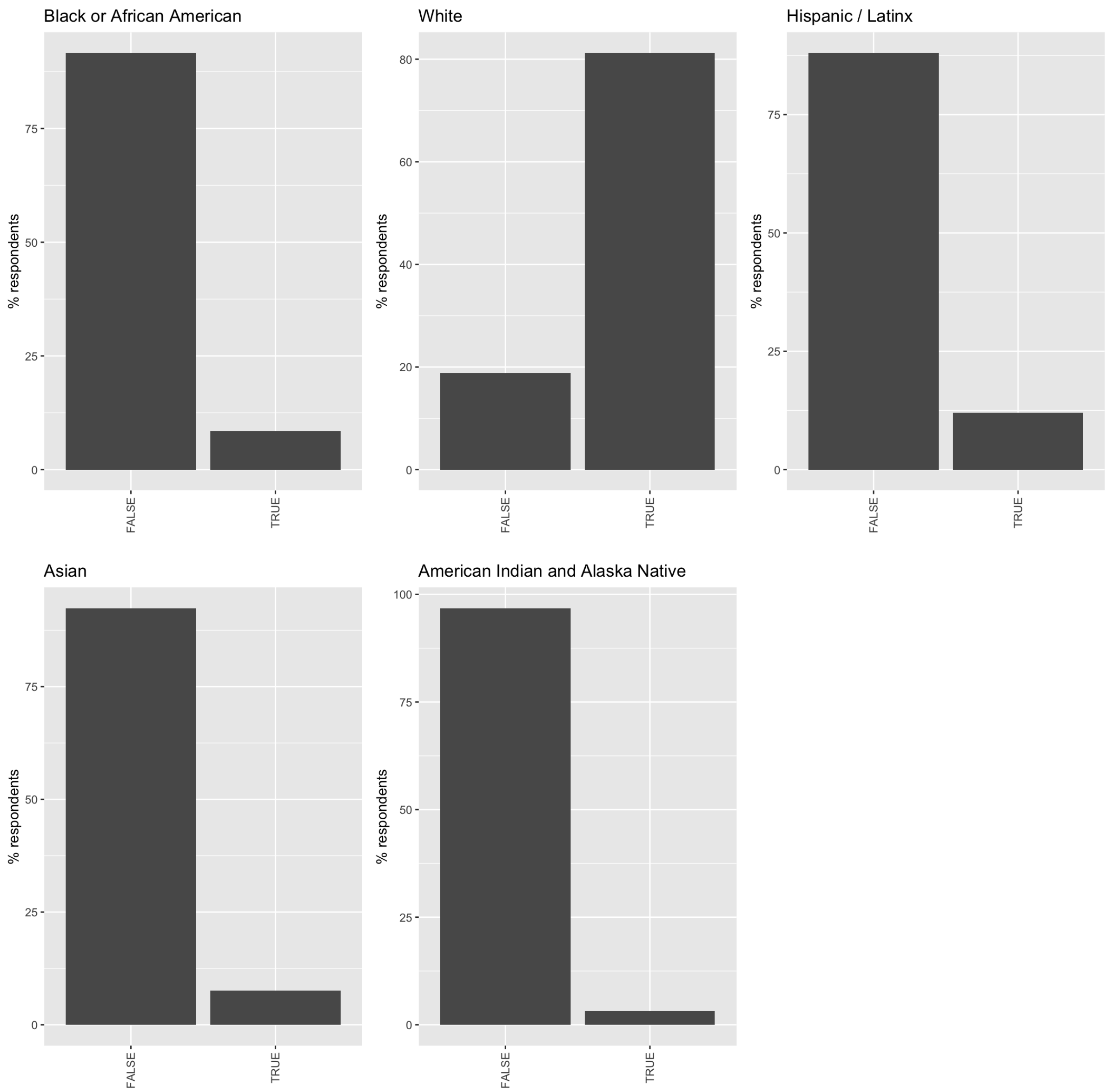

Figure S8: Racial / ethnic breakdown of respondents' children.

The survey analyses we present here are highly preliminary, and there remain many opportunities to further explore relationships between different responses and types of respondents. We release

[5]https://nces.ed.gov/programs/digest/d17/tables/dt17_204.10.asp.

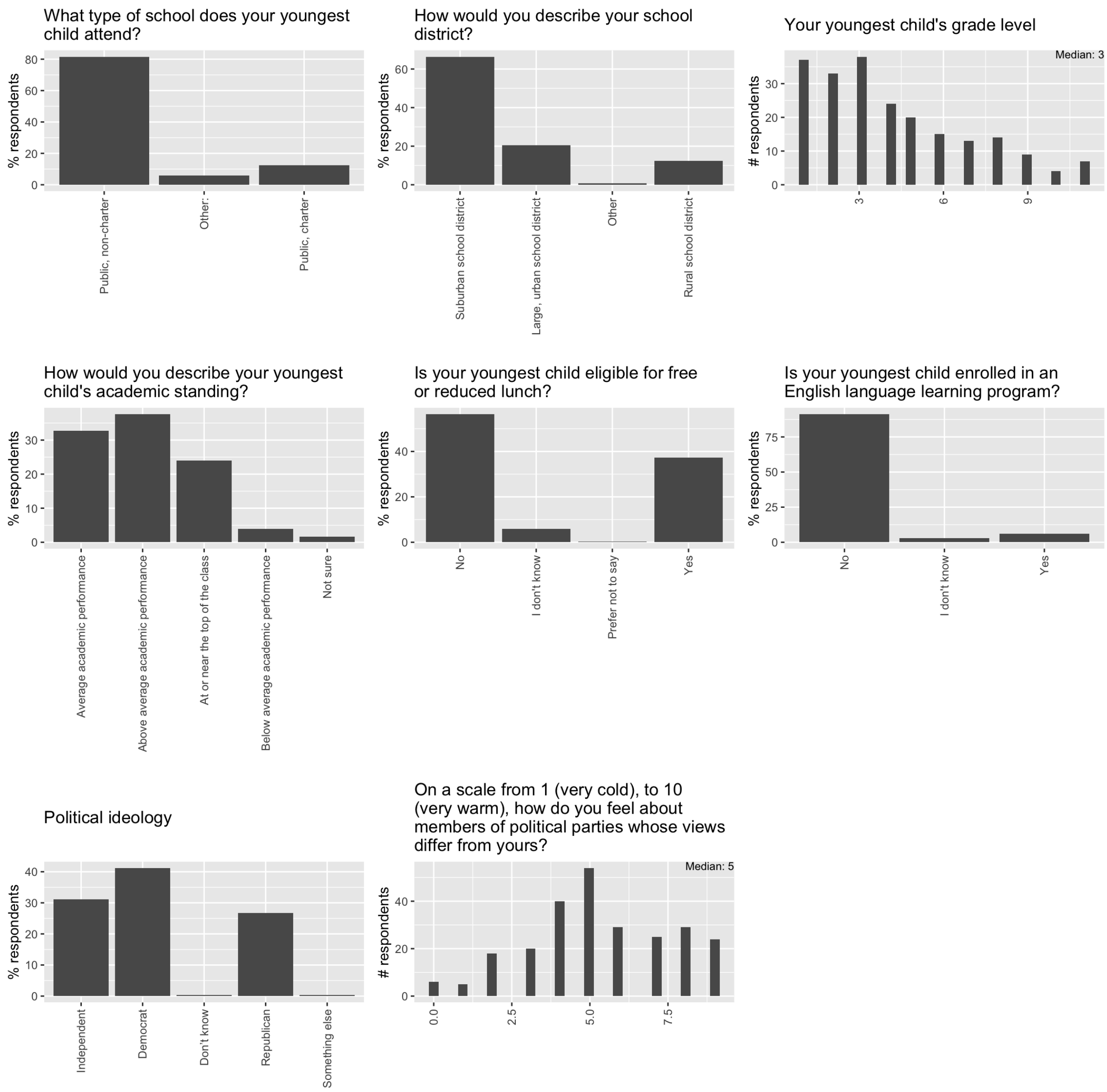

Figure S9: Responses to other post-treatment questions.

our survey data as part of the broader data release for this project in order to enable interested researchers to conduct these and other explorations.

S4 Additional results and sensitivity analyses

In this section, we include a number of additional results and sensitivity analyses / robustness checks to further contextualize the results presented in the main text.

S4.a Details on included/excluded school districts

Table S1 depicts the outputs of three generalized linear models (GLMs), denoted by the three corresponding columns. Model 1 is computed across all 4,231 districts in our broader sample and represents whether or not a district has open enrollment elementary schools varies as a function of the total number of students across races, as well as several measures of segregation (dissimilarity) describing the district. Model 2 is computed across the 3,970 districts that do

	Model 1	Model 2	Model 3
(Intercept)	0.06^{***}	0.03^{***}	0.07^{**}
	(0.00)	(0.00)	(0.02)
total_native	0.01	0.01^{***}	0.01
	(0.00)	(0.00)	(0.01)
total_black	0.01	0.04^{***}	0.01
	(0.00)	(0.00)	(0.01)
total_white	0.02^{***}	0.06^{***}	0.06^{***}
	(0.00)	(0.00)	(0.01)
total_hispanic	0.02^{***}	0.05^{***}	0.03^{**}
	(0.00)	(0.00)	(0.01)
total_asian	-0.00	0.03^{***}	0.02^{**}
	(0.00)	(0.00)	(0.01)
white_dissim	0.01^{**}	-0.00	0.06^{*}
	(0.01)	(0.00)	(0.03)
black_dissim	-0.01^{*}	-0.00	-0.00
	(0.00)	(0.00)	(0.03)
hisp_dissim	-0.00	-0.01^{*}	-0.02
	(0.01)	(0.00)	(0.03)
asian_dissim	0.00	-0.00^{**}	0.02
	(0.00)	(0.00)	(0.03)
AIC	-208.49	-6763.50	293.42
BIC	-138.64	-6694.34	336.20
Log Likelihood	115.25	3392.75	-135.71
Deviance	234.59	42.07	44.83
Num. obs.	4231	3970	361

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table S1: Statistical models

not have any open-enrollment elementary schools and represents how our selected districts (top 100) varies as a function of the same predictors. Model 3 is computed across the top 100 districts and the 6% (261) districts that *do* have at least one open-enrollment elementary school, and illustrates how our selected 100 districts vary as a function of the same predictors. As described in the main text, we can see that districts with open-enrollment elementary schools tend to have a slightly higher White population, slightly higher Hispanic/Latinx population, and slightly higher White/non-White segregation than those without. Furthermore, compared to the other 3,870 districts with no open-enrollment elementary schools, the selected 100 districts are (by definition) larger, but generally do not have higher levels of White/non-White segregation. Finally, compared to the excluded 6%, the selected 100 districts are also generally larger, and *do* have a higher level of White/non-White segregation. All independent variables have been scaled by subtracting the mean and dividing by the standard deviation for ease of interpretation.

S4.b Optimizing for probability of "cross-cutting" exposures

In a prototype analysis conducted prior to the one for this paper, we simulated alternative boundaries with the same constraints and values as described in the main text, but with a different objective: to maximize the probability of "cross-cutting exposures"—i.e., exposures between students from different backgrounds—across schools in the district. Our objective function was:

$$\Sigma_{sS}\ 2 \cdot p_s \cdot (1 - p_s) \tag{S8}$$

Where s is a particular non "open-enrollment" elementary school and p_g is the fraction of students at s who are White. Intuitively, $2 \cdot p_s \cdot (1 - p_s)$ measures the probability that any two students randomly drawn from school s are White and non-White. In this case, we did not weight by school size in order to treat schools across the district as fairly as possible (i.e., so gains in larger schools do not limit gains in smaller ones). The objective function is similar to the variance ratio index, but not normalized to make it a measure of evenness (12). It is also similar to the interaction index proposed by (9), except that it is defined with respect to individual schools instead of a broader geography of interest (e.g., the district or city). This means that the total sum across schools is not a probability (because it can sum to greater than 1), but enables us to interpret probabilities of cross-cutting exposures at the school level.

We simulated alternative boundaries for one state, Virginia, and not the same 98 districts as those studied in the main text of this paper. However, several of the 98 school districts are in Virginia. To compare and contrast results, we conduct two case studies—one using the objective function in the main text, the other, the function above—across two districts each: Henrico and Prince William Counties.

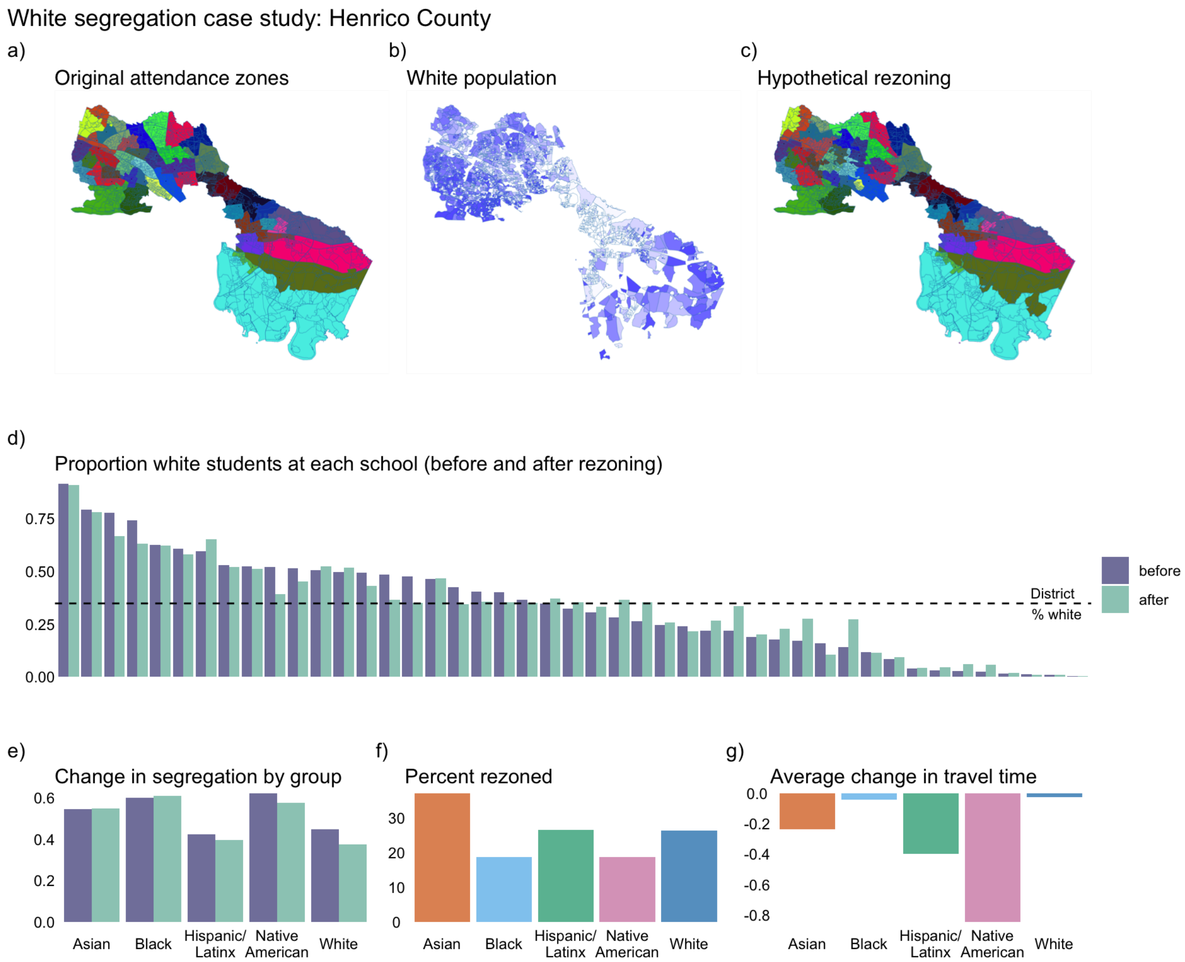

Figure S10: Virginia case study: Henrico, seeking to minimize the dissimilarity index from the main text.

Figures S10 and S11 show the case studies for Henrico when optimizing for dissimilarity and cross-cutting exposures, respectively. The same are shown for Prince William County in Fig-

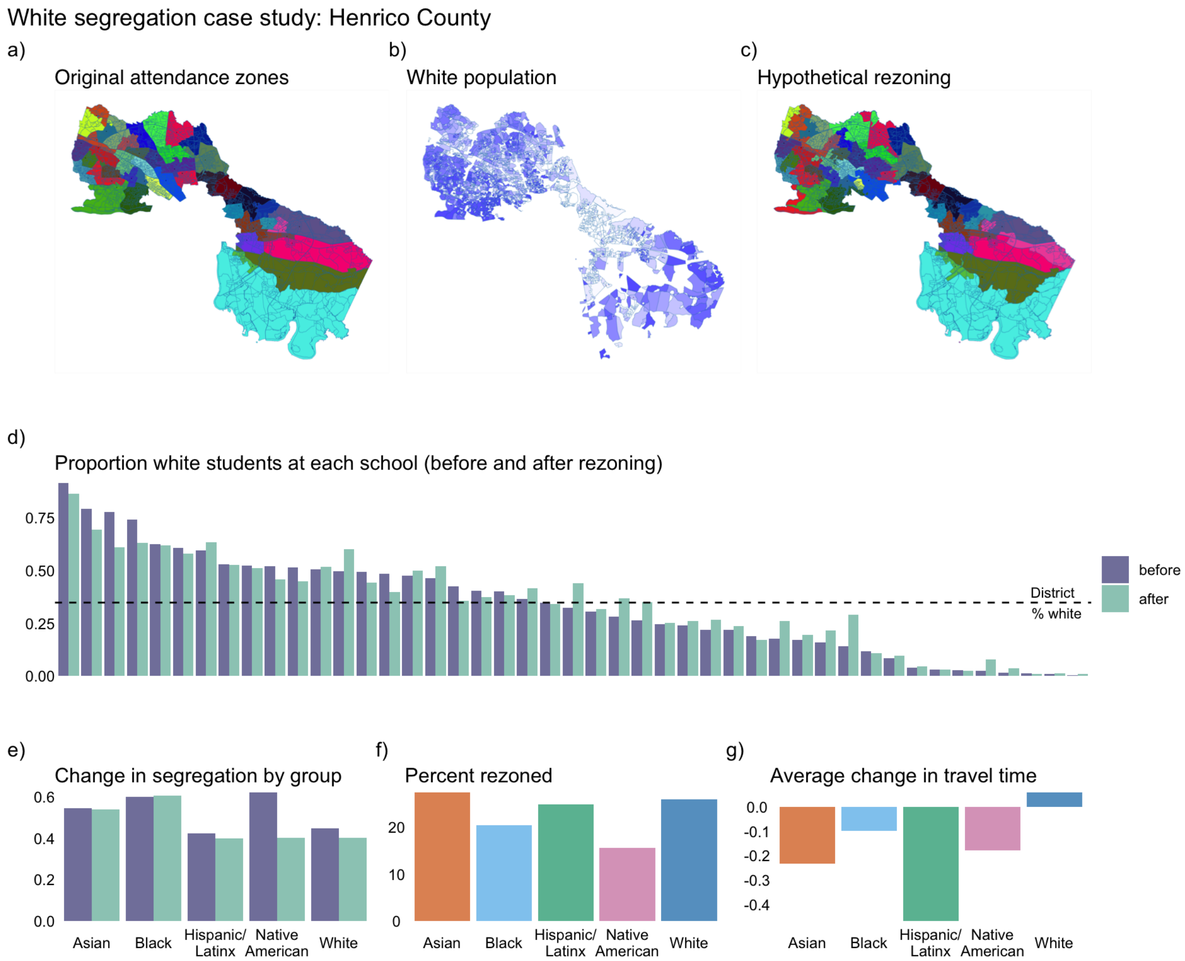

Figure S11: Virginia case study: Henrico, seeking to maximize the probability of cross-cutting exposures.

ures S12 and S13. In general, there appear to be slight differences in which schools experience demographic shifts depending on which objective function is used, with a qualitative read suggesting the dissimilarity-optimized case studies tend to drive more schools' White/non-White proportions closer to district levels. Furthermore, there are slight differences in the amount of segregation (dissimilarity) that is reduced (for Henrico, a decrease of 0.07 when optimizing for dissimilarity vs. 0.05 when optimizing for cross-cutting exposures; for Prince William, 0.03 vs 0.01). But in general, the results do not look dramatically different based on these different objective functions.

Given the breadth of potential objective functions that exist by virtue of the many different ways of measuring segregation that sociologists have explored over the decades (including those in (9)), a thorough analysis of how results vary across districts and different objective functions is beyond the scope of this paper. However, it is an important direction for future research, especially given that different objective functions may encode or reflect different properties that some districts find more or less desirable vis-a-vis their desegregation objectives.

S4.c Leximin objective function

As described in the main text, the dissimilarity index of segregation is a district-wide measure that doesn't account for how fairly segregation is redistributed across individual schools. In the spirit of "leximin" optimization (6), we produce rezonings that optimize the following objective

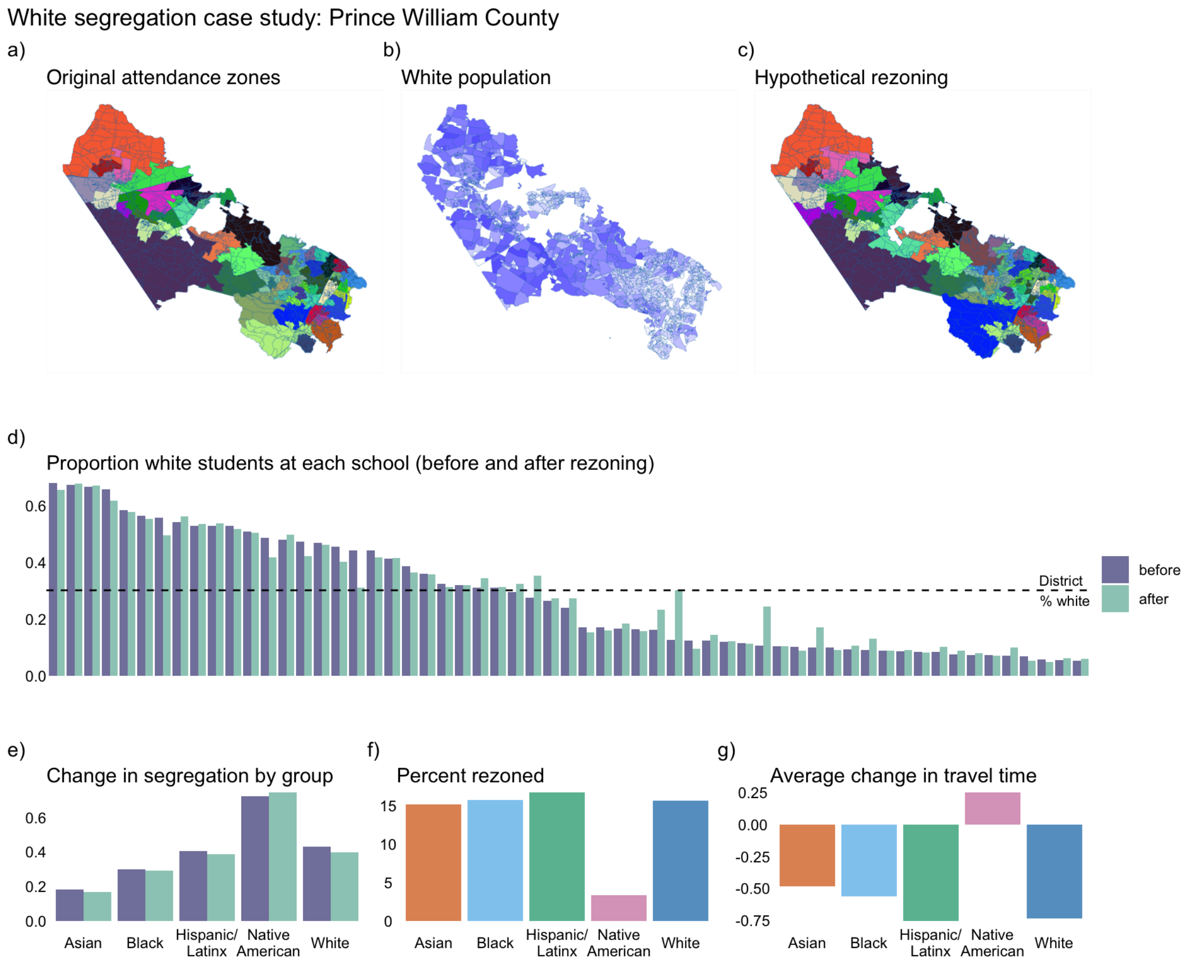

Figure S12: Virginia case study: Prince William, seeking to minimize the dissimilarity index from the main text.

function:

$$min\ max\ \forall_{sS}\ |\frac{W_s}{W_T} - \frac{NW_s}{NW_T}| \tag{S9}$$

I.e., we wish to minimize the maximum divergence of any school's White/non-White population from district-level proportions. Intuitively, this objective function seeks to prevent any particular school from experiencing a high level of segregation. Figure S14 shows results across districts under this alternative objective function. As expected, the overall reductions in segregation are lower than the primary results reported in the main text: just a 3% relative reduction in segregation compared to 12%. Furthermore, as shown in the Atlanta case study (Figure S15(d)), there still appear to be several schools with White over-representation in the status quo zoning that *increase* in their percentage of White students after rezoning, instead of decreasing as we might expect—similar to Figure 4(d) in the main text. The same is true in the Mesa Unified case study (Figure S16). For these particular case studies, the minmax objective function does not appear to dramatically balance out how much each school's White/non-White populations diverge from district-wide levels. Other formulations of the objective function, and/or additional constraints that seek to achieve a more equitable distribution across schools may more effectively balance out demographic distributions while still reducing district-wide segregation levels.

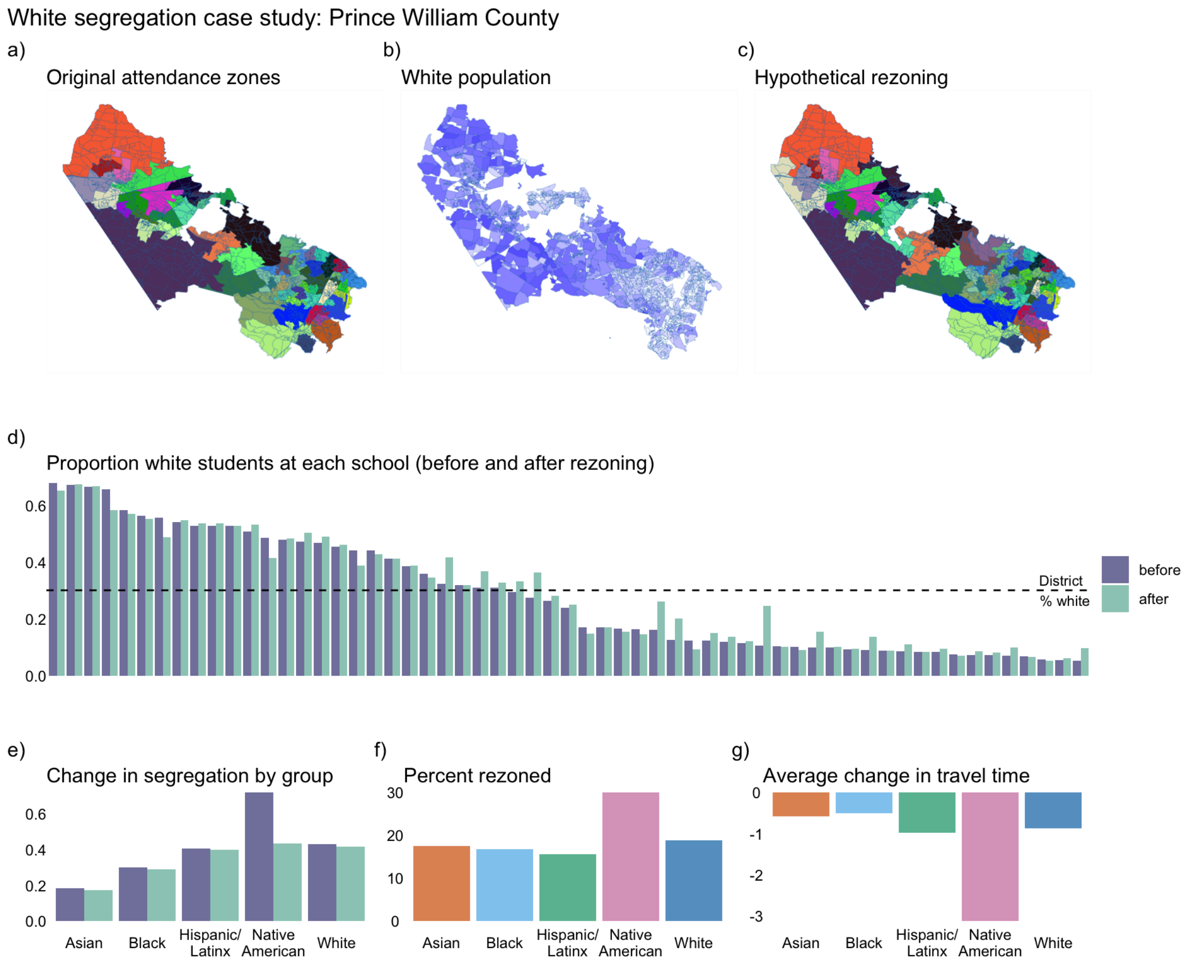

Figure S13: Virginia case study: Prince William, seeking to maximize the probability of cross-cutting exposures.

S4.d Increasing travel times

As discussed in the main text, increasing the permissible limit on travel time increases to 100% (or 2x current travel times) decreases median segregation by 16% relative to baseline levels, compared to a 12% reduction when the travel time increase is capped at 50%. Figure S17 illustrates these results. Looking at Figure S18, we see that several additional schools in the Atlanta case study with high non-white segregation see more racial balancing under this configuration; the same applies to the Mesa Unified case study (Figure S19).

S4.e Dropping contiguity constraint

As discussed in the main text, removing the contiguity constraint produces a sizeable 40% relative median reduction in segregation across districts. Figure S20 illustrates these results. Again, looking at Figure S21, we see even more schools converging to district-wide levels of White/non-White students, though this time at the expense of some schools that were already very close to district-wide levels experiencing large increases in the percentage of students who are white. Mesa Unified (Figure S22) also experiences convergence to district-level proportions across many of its schools, with fewer instances of dramatic over-concentration of White students in comparison to Atlanta post-rezoning.

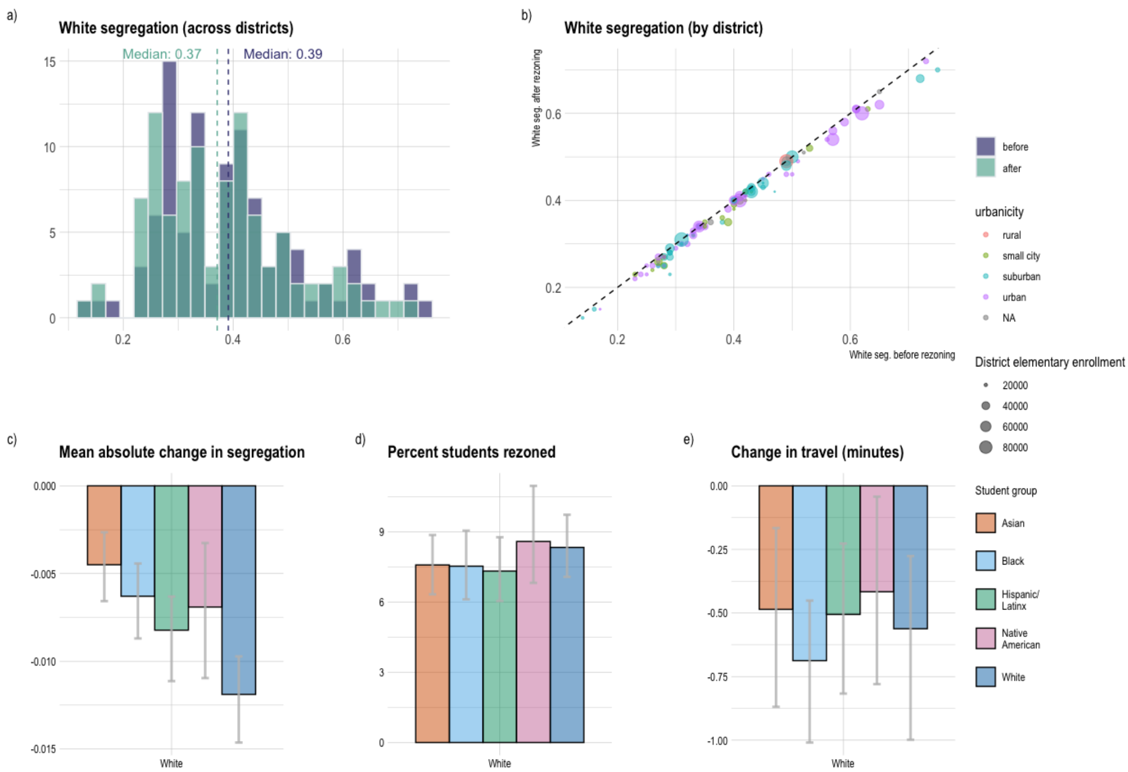

Figure S14: Aggregate results from minmax optimization.

S4.f Increasing travel times *and* dropping contiguity

Simultaneously loosening the travel increase constraint to 100% *and* removing the contiguity constraint produces a 65% relative median reduction in segregation across districts. Figure S23 illustrates these results. Once again, several schools in Atlanta (Figure S24) experience a further over-concentration of White students, though several more converge to district-wide proportions, as expected. In Mesa Unified (Figure S25), we also see converge of many schools' White/non-White populations to district-wide averages, again with fewer schools than Atlanta experiencing significant over-concentration of White students post-rezoning.

Together, the sensitivity analyses in this and preceding sections illustrate how changing constraint values can impact the extent to which alternative attendance boundaries might reduce segregation across school districts. They also illustrate the trade-offs district leaders might be faced with making, like demographic changes in certain schools versus others, to achieve such district-wide reductions in segregation.

S5 Data and code release

While we focus on presenting both aggregated results and a deeper dive into two of our 98 school districts throughout the main text and supplementary materials, interested readers are invited to explore a public dashboard detailing results for additional districts in our study: LINK TO DASHBOARD.

Additionally, we release an online repository of code used to produce the main and supplementary analyses in this paper, which can be found here: LINK TO REPOSITORY. Additionally, we release several datasets to aid replications and future research. A summary of these datasets

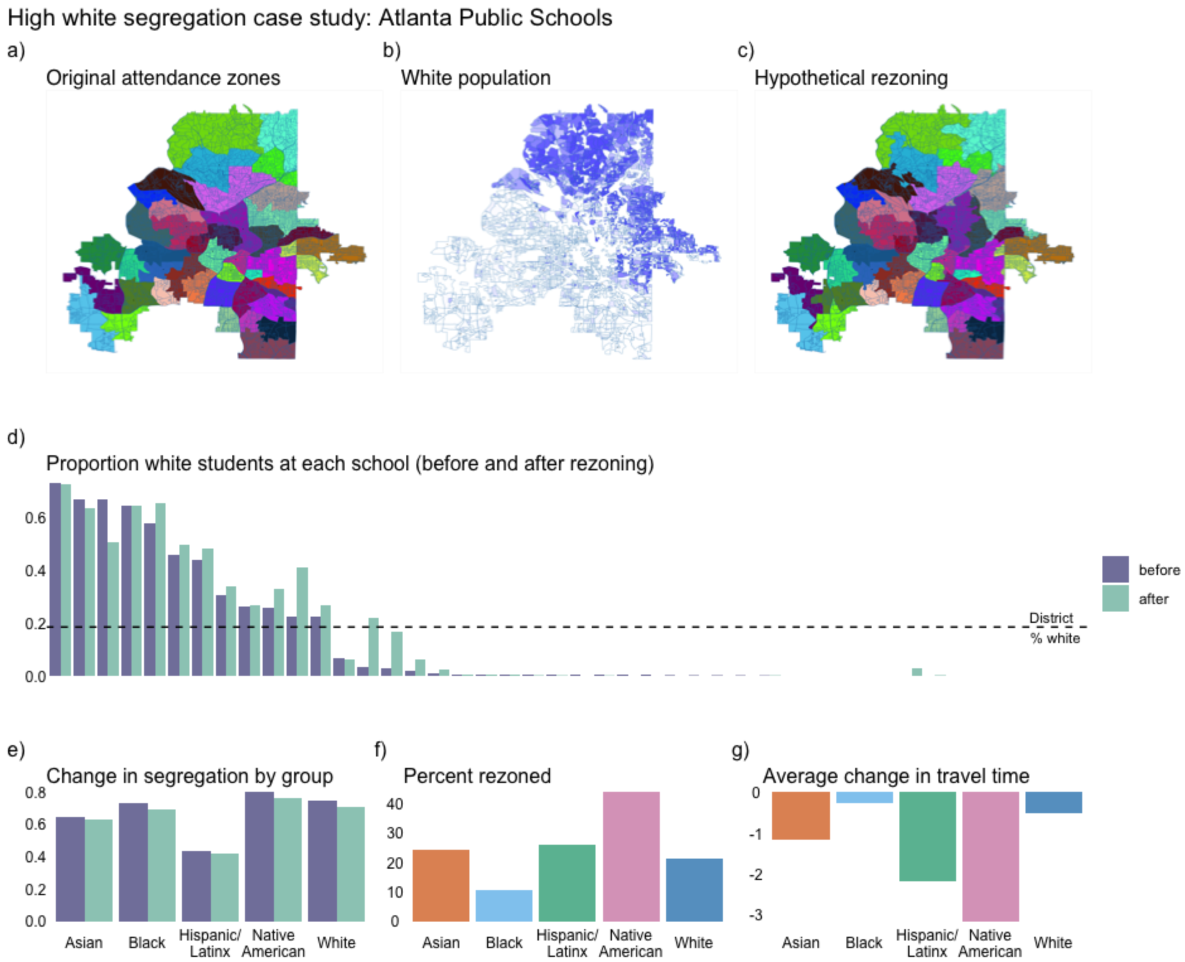

Figure S15: Atlanta case study under minmax optimization.

is included below, with additional details available in the repository's README file. We include data at the district level for all US school districts with at least two non open-enrollment elementary schools.

- Mapping of Census blocks to zoned elementary schools
- Estimated student counts per racial/ethnic category, per block
- Matrix of estimated driving times from blocks to schools
- Networks representing adjacency relationships between blocks (used for contiguity)
- Various district-level covariates for the districts included in our study
- Raw data from parent survey

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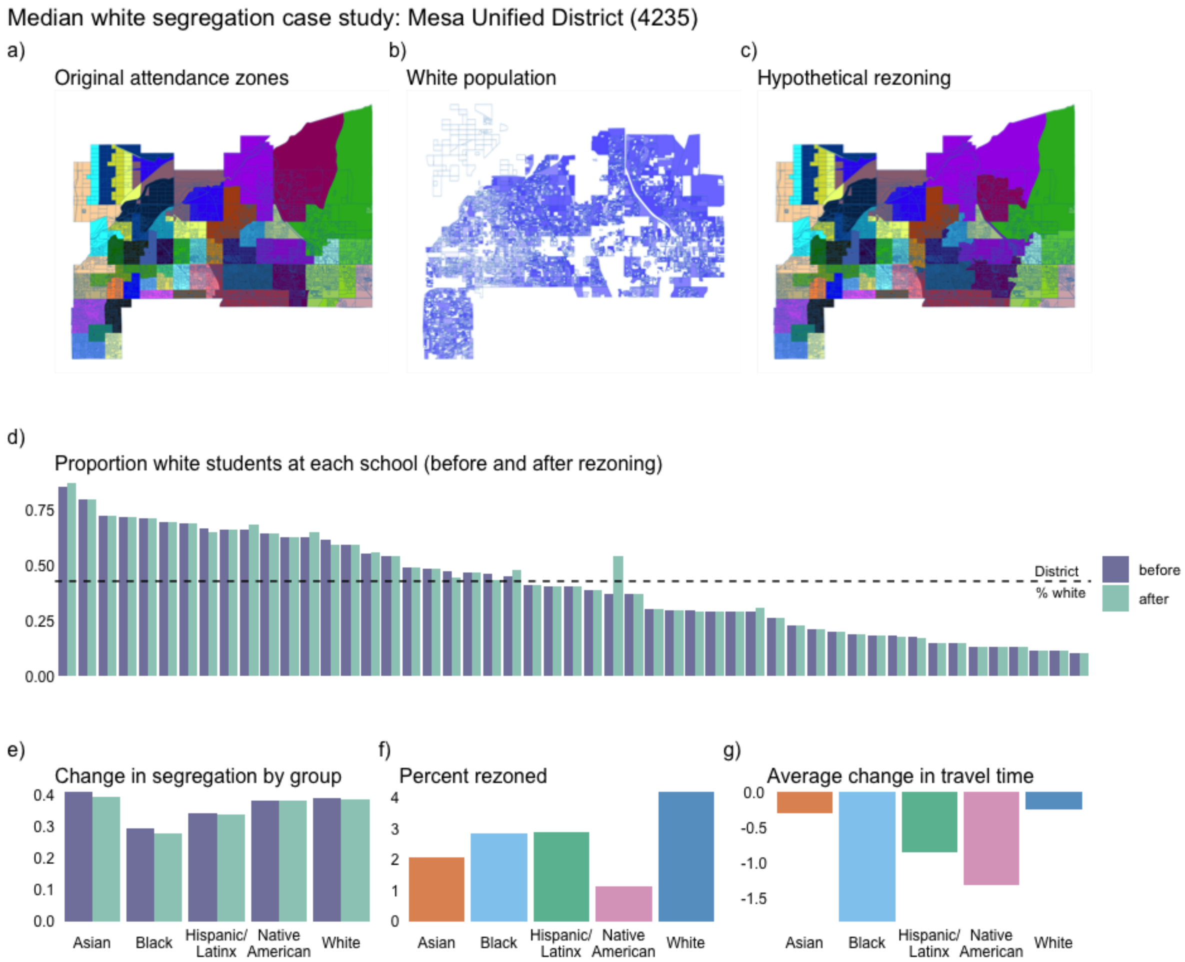

Figure S16: Mesa unified case study under minmax optimization.

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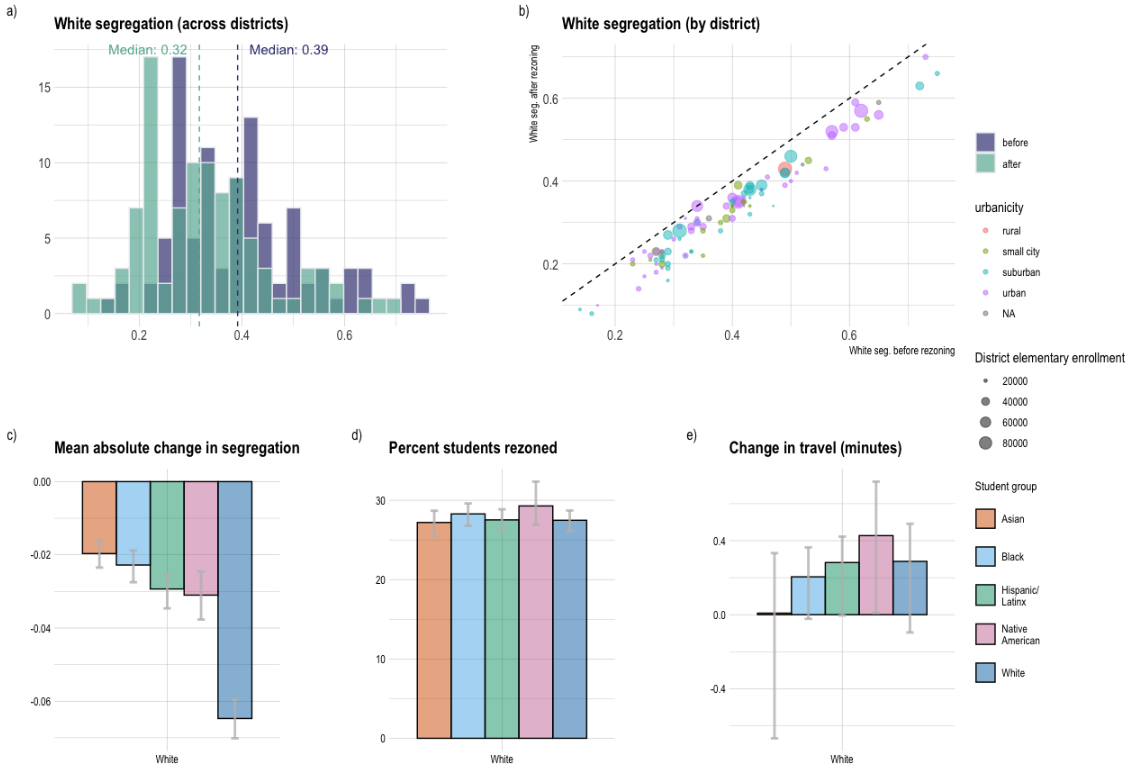

Figure S17: Aggregate results from optimization with looser travel constraint.

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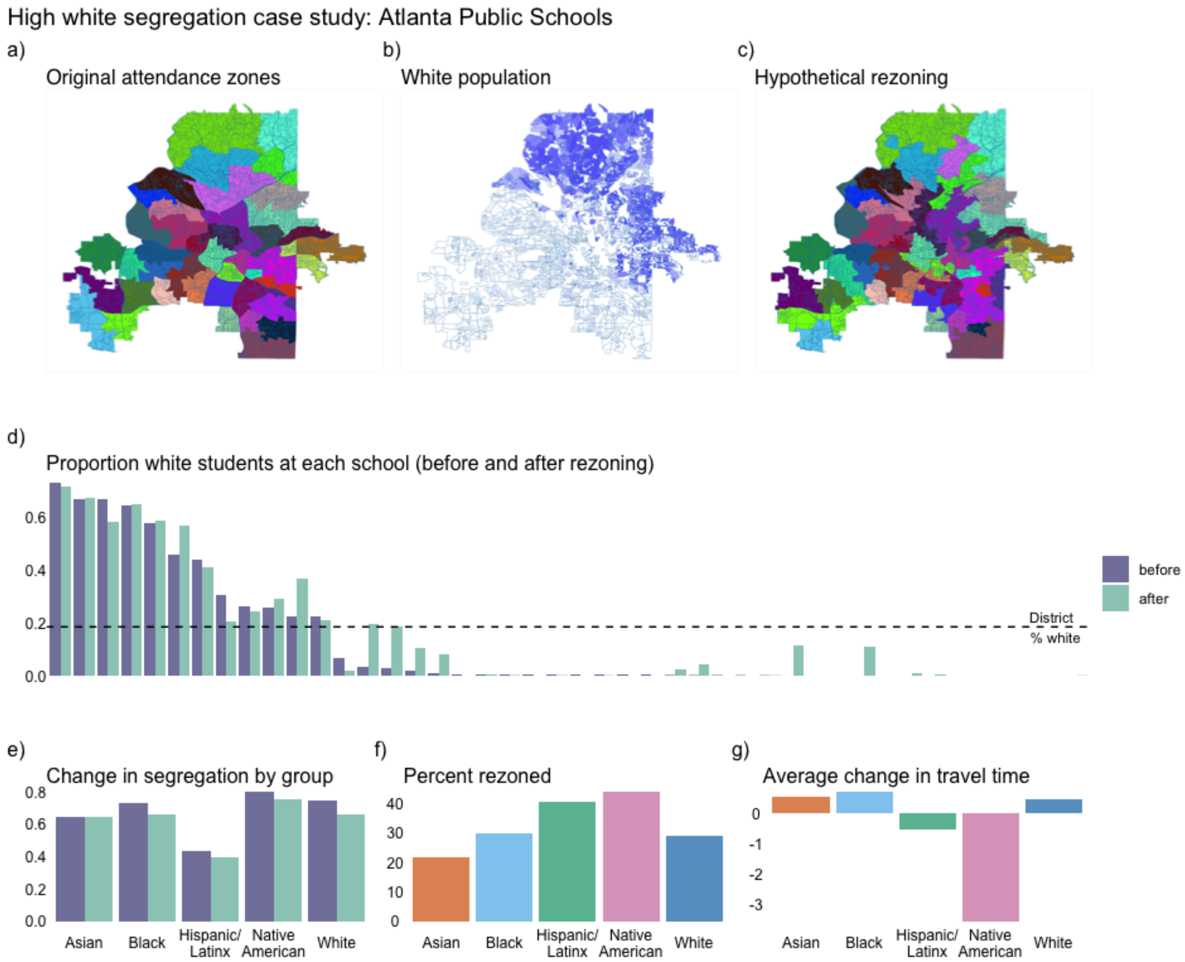

Figure S18: Atlanta case study with looser travel constraint.

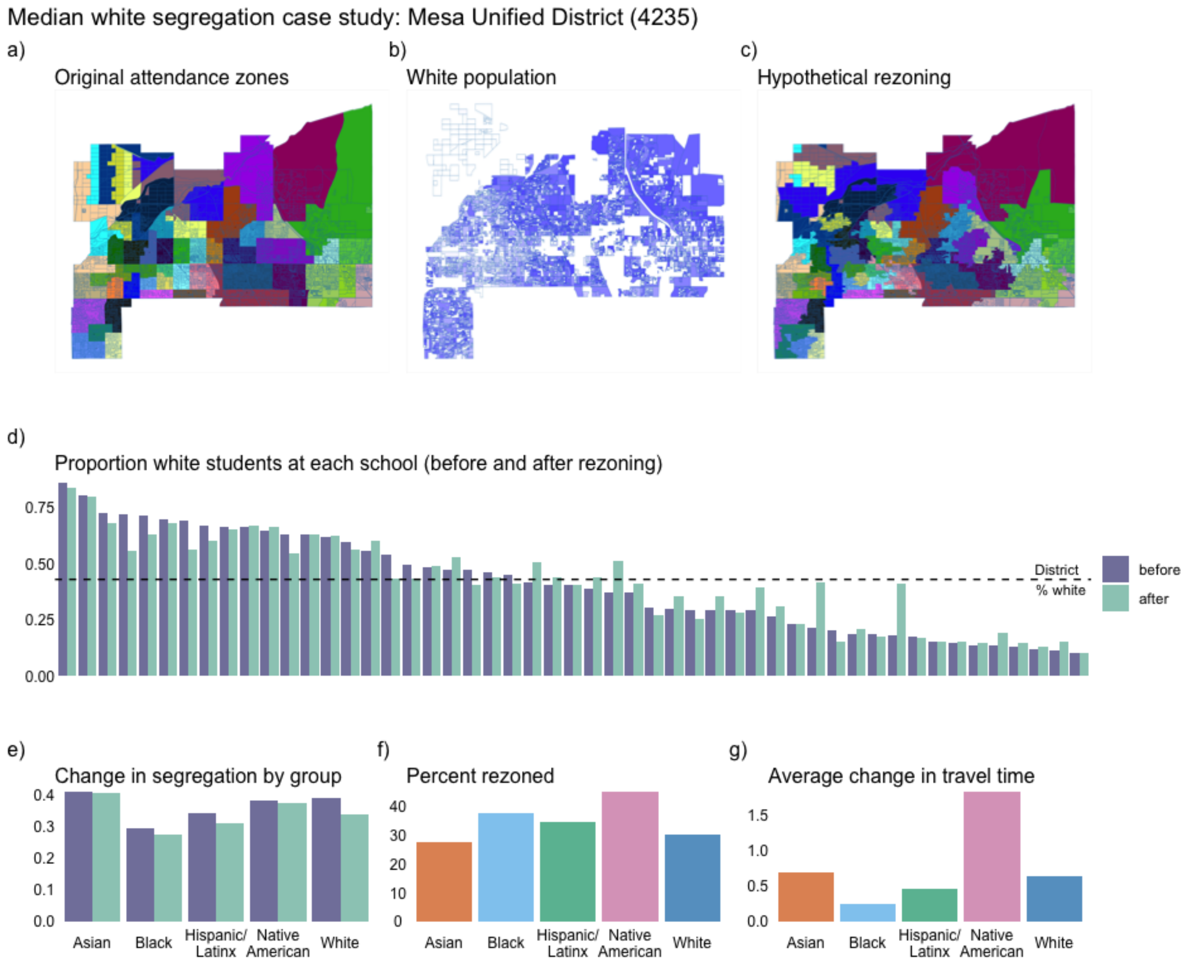

Figure S19: Mesa unified case study with looser travel constraint.

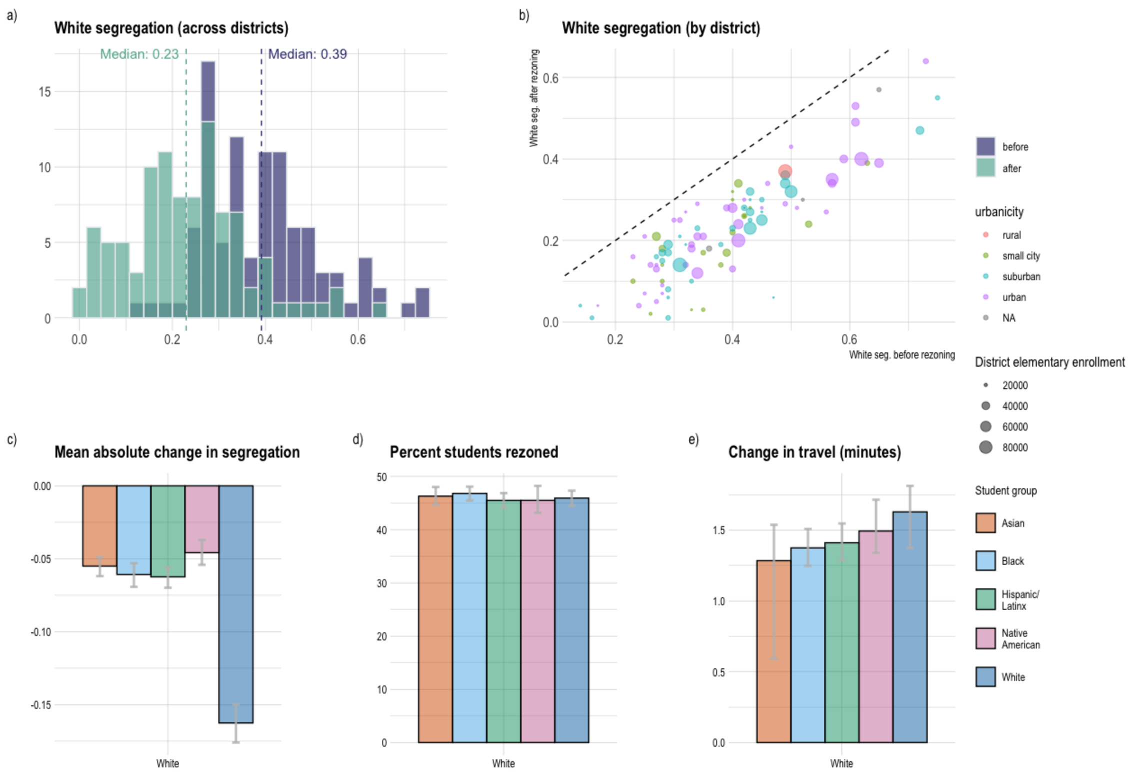

Figure S20: Aggregate results from optimization with no contiguity constraints.

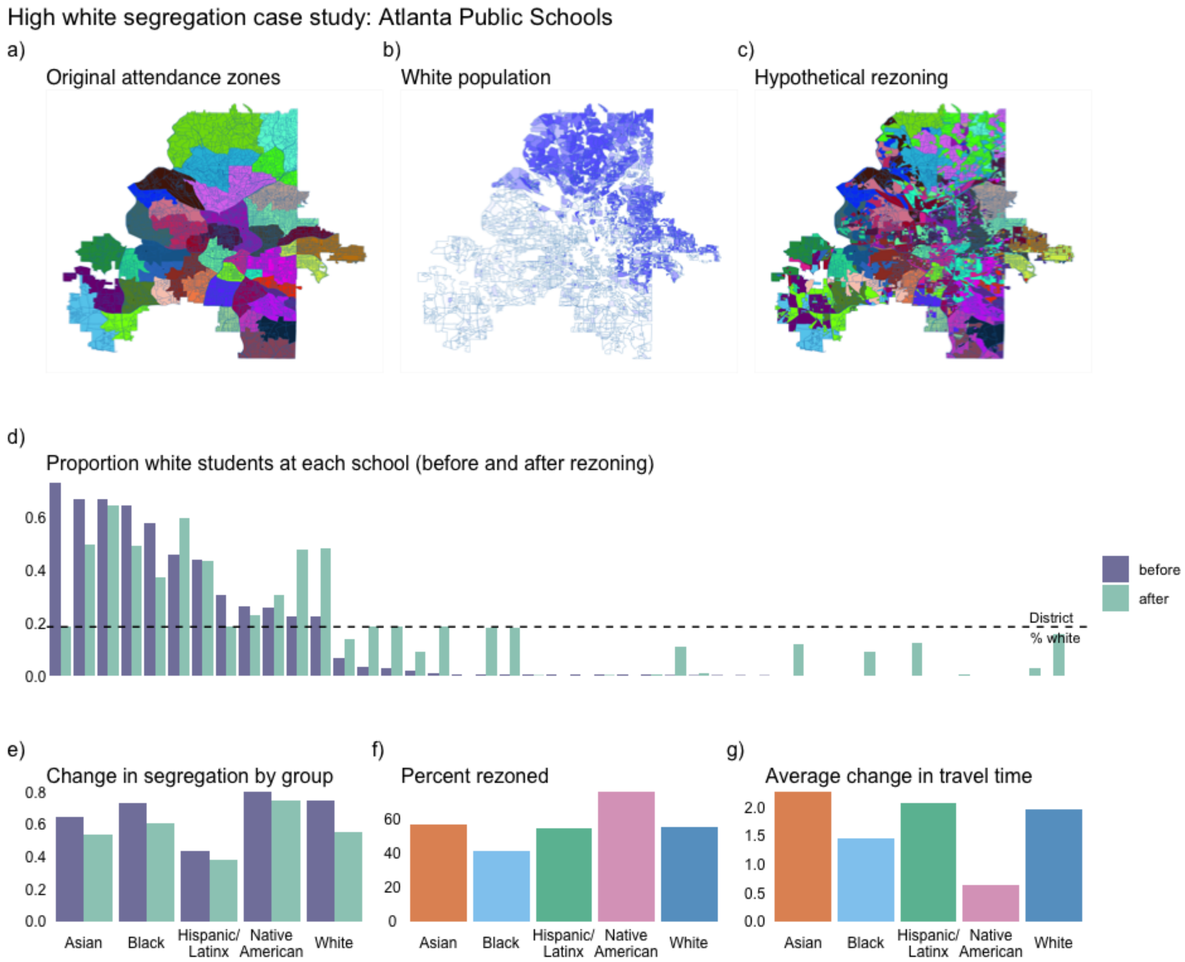

Figure S21: Atlanta case study with no contiguity constraints.

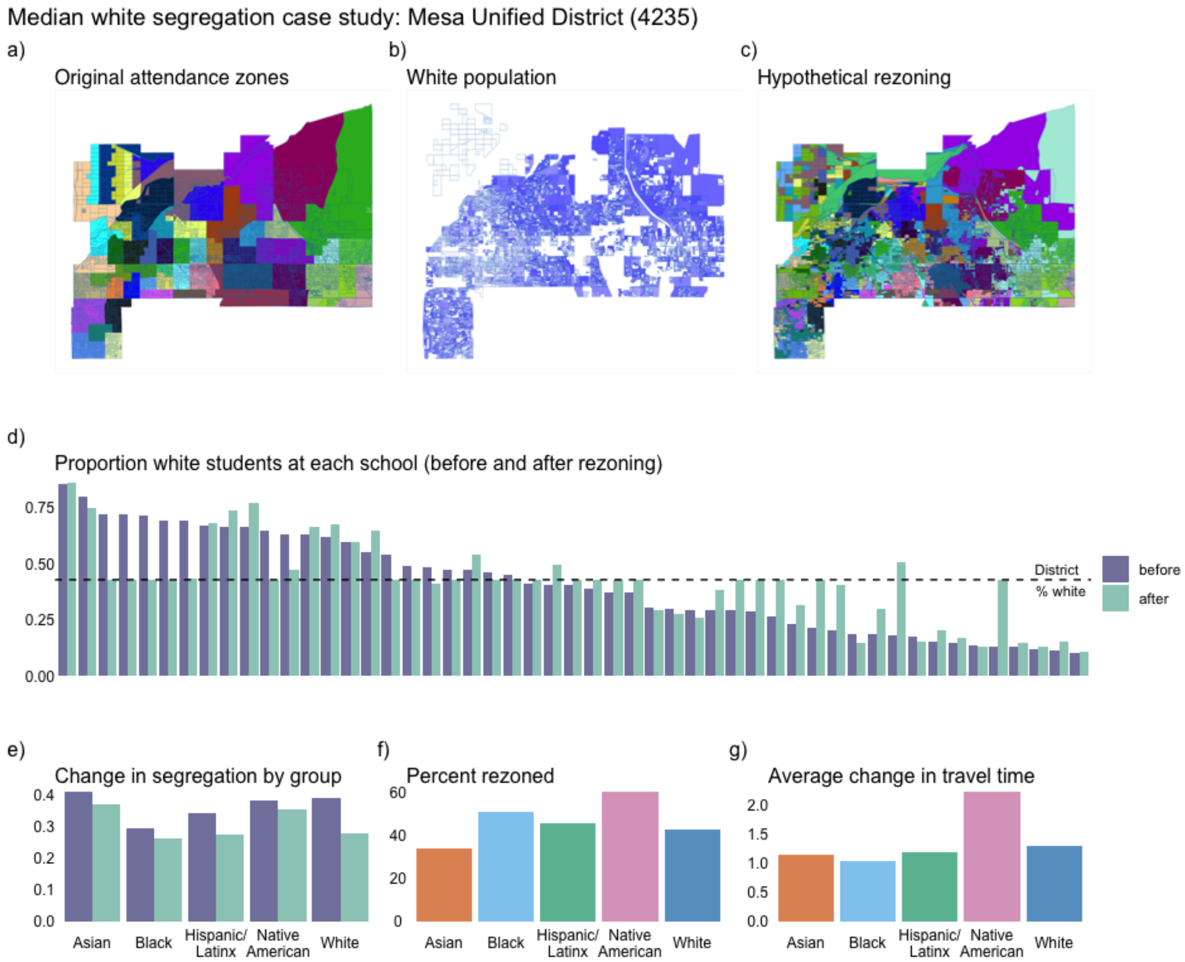

Figure S22: Mesa unified case study with no contiguity constraints.

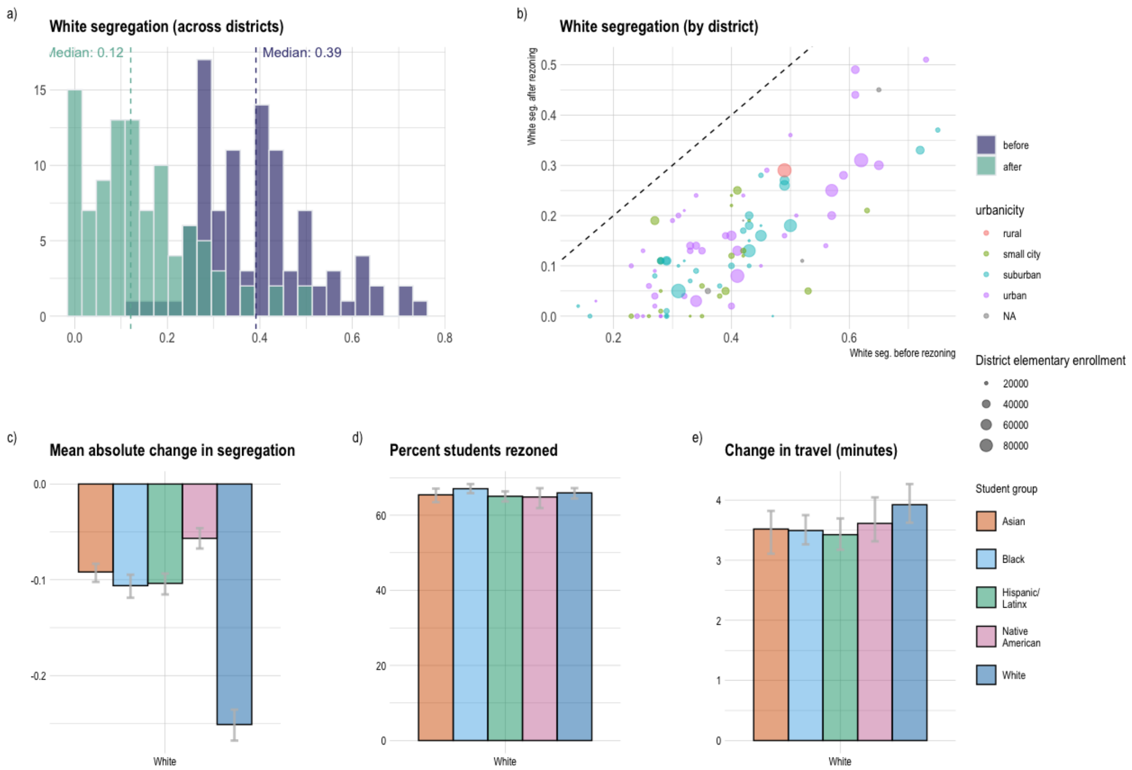

Figure S23: Aggregate results from optimization with looser travel constraint and no contiguity constraints.

Figure S24: Atlanta case study with looser travel constraint and no contiguity constraints.

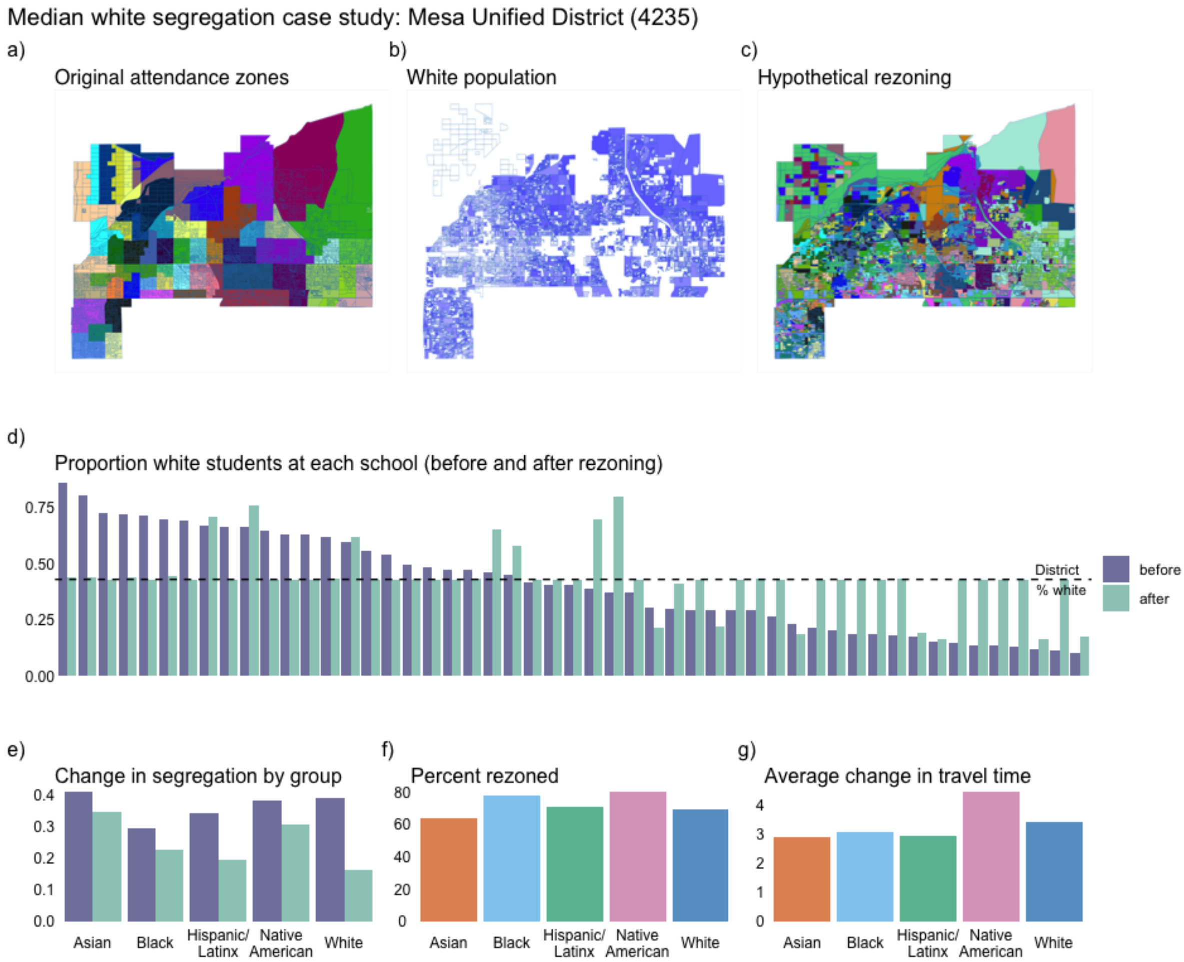

Figure S25: Mesa unified case study with looser travel constraint and no contiguity constraints.