

**ORIGINAL ARTICLE**

# Illuminating inequality in access: Variation in enrollment in undergraduate engineering programs across Virginia's high schools

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**Abstract**

**Background:** Determining the root causes of persistent underrepresentation of different subpopulations in engineering remains a continued challenge. Because place-based variation of resource distribution is not random and because school and community contexts influence high school outcomes, considering variation across those contexts should be paramount in broadening participation research.

**Purpose/Hypothesis:** This study takes a macroscopic systems view of engineering enrollments to understand variation across one state's public high school rates of engineering matriculation.

**Design/Method:** This study uses a dataset from the Virginia Longitudinal Data System that includes all students who completed high school from a Virginia public school from 2007 to 2014 ( $N = 685,429$ ). We explore geographic variation in four-year undergraduate engineering enrollment as a function of gender, race/ethnicity, and economically disadvantaged status. Additionally, we investigate the relationship between characteristics of the high school and community contexts and undergraduate engineering enrollment across Virginia's high schools using regression analysis.

**Results:** Our findings illuminate inequality in enrollment in engineering programs at four-year institutions across high schools by gender, race, and socioeconomic status (and the intersections among those demographics). Different high schools have different engineering enrollment rates among students who attend four-year postsecondary institutions. We show strong associations between high schools' engineering enrollment rates and four-year institution enrollment rates as well as moderate associations for high schools' community socioeconomic status.

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**Conclusions:** Strong systemic forces need to be overcome to broaden participation in engineering. We demonstrate the insights that state longitudinal data systems can illuminate in engineering education research.

**KEYWORDS**

diversity, engineering pathways, high school, higher education

## 1 | INTRODUCTION

Despite continued investments in recruitment and outreach initiatives, undergraduate engineering still lacks representation from broad segments of the population, some of which are among the fastest growing demographics in the United States. Determining the root causes of this persistent underrepresentation remains a continued challenge for researchers. Whereas much research focuses on how and why individuals make specific choices, less research focuses on systemic issues. Our research answers recent calls to interrogate systems (Pawley, 2019), or as Lee argued in his *Journal of Engineering Education* editorial, situations “in which participants are acted upon by a surrounding system and have little agency to change their course” (Lee, 2019, p. 10). We focus at the macroscale and investigate broad inequities in access to engineering, recognizing there are many variables that do not occur randomly but rather are systematically interconnected.

Given the amount of research focused on the K-16 pathway and its relationship with broadening participation in engineering, the paucity of research focused on ways that students' high school contexts (representing a system) relate to their postsecondary major choice is surprising (Goyette & Mullen, 2006). A systems analysis that thinks holistically about high school level variables combines variables such as course offerings, extracurricular activities, peer environments, and access to well-informed guidance counselors and teachers that influence how students prepare for college (Adelman, 1999; Kahne & Bailey, 1999; McDonough, 1997, 2005; Plank & Jordan, 2001; Roderick, Nagaoka, Coca, & Moeller, 2008; Roscigno & Crowley, 2001). Simultaneously, parental influences and the surrounding community constitute most of students' social and cultural capital, which are linked in part to their subsequent major choices (Astin, 1993; Carrico & Matusovich, 2016; Simpson, 2001). Because place-based variation of resource distribution and human capital is not random (Florida, 2002), and because school and community contexts directly influence high school outcomes (e.g., Chetty, Hendren, & Katz, 2016; Hannaway & Talbert, 1993; McDonough, 1997; Roscigno & Crowley, 2001; Shouse, 1998), considering variation across those contexts—as we do in our paper—should be paramount in research on broadening engineering participation.

Using a state longitudinal data system, our paper takes a macroscopic systems view of one state's population of high school to postsecondary students to understand variation regarding graduating student enrollment in engineering across each public high school. We explore how engineering enrollment rates vary across high schools for different demographic groups. At its core, this paper illuminates unequal rates in enrollment in engineering programs at four-year institutions across high schools and depicts how variables systematically related to high school context or geography (i.e., place-based characteristics) can act in combination to restrict access to undergraduate engineering. Specifically, we address the following research questions:

**RQ1:** What is the geographic variation in four-year undergraduate engineering enrollment across Virginia's high schools as a function of gender, race/ethnicity, and economically disadvantaged status?

**RQ2:** What is the relationship between undergraduate engineering enrollment and characteristics of the high school and community contexts across Virginia's high schools?

## 2 | TERMINOLOGY

A range of terms has been used to refer to minoritized groups across the literature as well as in the archival data sets from which we draw. The Virginia Longitudinal Data System collects “gender” information as a binary male and female variable. We recognize that much of the literature uses the terms gender and woman/man or girl/boy, and we

further recognize that gender also is not binary nor are gender and sex interchangeable. We discuss our findings using the social construct “gender” term since we argue that the surrounding system makes a student minoritized but want to note the limitation in how data were collected by the state agency using a binary male/female variable.

For race/ethnicity, we describe students as being minoritized or use the term “underrepresented minority (URM)” —this abbreviation is consistent with National Science Foundation reporting norms (see, for example, *Women, Minorities, and Persons with Disabilities in Science and Engineering*, Falkenheim, Burke, Muhlberger, & Hale, 2017). Students who are categorized as American Indian or Alaska Native, Black, Hispanic, Native Hawaiian or Pacific Islander, and Non-Hispanic two or more races (i.e., students report Hispanic ethnicity separately from race and are all included as URM) are considered minoritized in the engineering context. We frame our discussion as the surrounding system being the reason for inequality as opposed to an individual student characteristic causing inequality.

Finally, consistent with Virginia Department of Education reporting, we use the term “economically disadvantaged” to refer to students who are eligible for free/reduced meals, receive Temporary Assistance for Needy Families (TANF), -are eligible for Medicaid, identified as migrant, or experienced homelessness. This term is similar to others used in engineering education, such as “socioeconomically disadvantaged” (e.g., Major, 2019), and importantly frames the causes of inequality on the social context within which a student resides as opposed to aspects of the students themselves.

### 3 | CONCEPTUAL FRAMEWORK

We conceptualize our study using Perna's (2006) model of student college choice, which brings together research from econometric and sociocultural perspectives regarding influences on postsecondary decision processes. Although she focused on a “college choice” outcome, similar influences help determine major choice, including gender (e.g., Jacobs, 1986, 1995), race (e.g., Thomas, 1985), ethnicity (e.g., Simpson, 2001), labor market returns (e.g., Cebula & Lopes, 1982; Davies & Guppy, 1997), and parental and community contexts (Bourdieu & Passeron, 1977, 1979; Carrico, Matusovich, & Paretto, 2017; Simpson, 2001). Perna's (2006) synthesis of prior research demonstrates that students' decision processes are embedded within a larger sociocultural context that must be considered when understanding why students think and act in certain ways. Perna scaffolds this idea into “habitus” (i.e., internal values driven by students' immediate environment); school and community context; higher education context; and social, economic, and policy context layers. Our research seeks to contribute new knowledge within the school and community contextual layer, where prior macroscale research on major choice has been more limited (Goyette & Mullen, 2006). Perna's (2006) model provides the direction for our analyses (i.e., a conceptual framework) and interpretation of findings, but we did not aim to explicitly test or verify any aspect of the model.

### 4 | LITERATURE REVIEW

Students' access to social networks and resources varies largely from school to school and from community to community. As McDonough (1997) articulates, social structures and resources that behave as a function of school and community contexts can support or restrict students' college-going behavior. Similarly, Perna and Titus (2005) showed that the amount of economic, cultural, and social capital that a school affords via its social networks, measured by school-level averages of family income, parental education, and parental involvement, relates to college enrollment rates of students from that high school. Thus, where students attend high school matters as they form their postsecondary plans.

#### 4.1 | Organizational and school resources: Systems influencing major choice

Organizational resources (e.g., budgets for hiring teachers and counselors, facilities, cocurricular offerings) matter for postsecondary pathways. Studies often use school size as a proxy for economies-of-scale or available organizational resources (Lee, 2000), yet the evidence for high school size effects on different outcomes is mixed. Leithwood and Jantzi (2009) summarize that studies using U.S. nationally representative longitudinal samples as well as many using statewide public school data report advantages for moderate-size (e.g., 600–1,000) schools include learning (Howley & Bickel, 1999; Lee & Smith, 1997), achievement equity (Bickel, Howley, Williams, & Glascock, 2001; Lee & Smith, 1997), student engagement (Weiss, Carolan, & Baker-Smith, 2010), and student retention (Gardner, Ritblatt, & Beatty, 1999).

However, a raft of other studies examining math achievement or gains show very small to no direct school size effects (Weiss et al., 2010; Wyse, Keesler, & Schneider, 2008), curvilinear effects favoring smaller and larger schools (Werblow & Duesbery, 2009), or effects for large schools (Lindahl & Cain Sr, 2012; Schreiber, 2002), including for Black students (Greeney & Slate, 2013).

School resources, often linked specifically to school size, influence postsecondary choices and may matter more for particular disciplines. For example, Engberg and Wolniak (2010) found that students who attended academically rigorous high schools, measured using school-wide aggregates of the highest level of mathematics taken, total number of advanced placement courses taken, and high school grade point average, were more likely to enroll in any college and attend a four-year college. Specifically for engineering enrollments, offering advanced science, technology, engineering, and mathematics (STEM) courses is important (Holdren & Lander, 2012), and school size influences course offerings as large schools are more likely than small schools to offer such academically advanced courses (Lee, Smerdon, Alfeld-Liro, & Brown, 2000). Of particular relevance to college-going and engineering-majoring are Schreiber's (2002) findings that larger schools, defined by number of teachers, had both more advanced placement calculus teachers and higher math achievement for students in advanced math classes. Thus, although the literature suggests school size relates to some student outcomes, the relationships are unclear and likely reflect complex indirect as well as direct phenomena. Examining high school size in relation to engineering enrollment may shed light on some of these complexities. To our knowledge, this approach is novel; we were unable to locate prior studies examining the connection between school size, captured in our study by the number of high school completers, and major choice.

## 4.2 | School and community contexts: Interrelated variables influencing major choice

School and community contexts systematically encapsulate other variables that influence major choice. Specifically, we consider geography of opportunity, physical geographic differences, and socioeconomic and demographic geography.

Research on geography of opportunity has documented the importance of where people live in determining their access to educational opportunities and resources (Green, Sánchez, & Germain, 2017; Hillman & Weichman, 2016). For example, in a qualitative study of Appalachian youth, Carrico and Matusovich (2016) found that social and family networks, such as parental place of employment, influenced knowledge of the college application process. Other prior work examining high school and community contexts has found that urban and rural schools are more similar to each other than to suburban schools regarding levels of family and school resources (Rosigno, Tomaskovic-Devey, & Crowley, 2006). Using the National Education Longitudinal Study to identify differences among students from urban, suburban, and rural high schools, Hu (2003) showed that if urban students did not drop out of high school, they attended a postsecondary institution at the same rate as suburban students; rural students were disadvantaged in terms of access (Hu, 2003). And prior work with the MIDFIELD database showed that students from high-poverty schools were fairly unlikely to major in engineering, although those numbers increased from 1994 to 2003 (Lundy-Wagner et al., 2014).

In addition to socioeconomic differences, physical geographic distances of some rural communities to postsecondary institutions create unique complications for rural students. Byun, Irvin, and Meece (2015) found that rural youth were less likely than their nonrural counterparts to attend a selective institution, delayed entry to postsecondary education, and were less likely to be continuously enrolled; there is also a lower expectation that children will attend college when parents are less likely to have a bachelor's degree. In the rural regions of Virginia, for example, only 27% of the population holds an associate's degree or higher, compared to 51% for the state and 46% for the nation (U.S. Department of Education, 2017; State Council of Higher Education for Virginia, 2017). Thus, socioeconomic status and access to particular resources influence students' postsecondary pursuits and are systematically situated geographically.

In a related study, economic geography research by Florida (2002) suggests that there is spatial variation in the United States in human capital, measured as a composite of the percentage of the population with at least a bachelor's degree, workers in the professional and technical fields, and workers in science or engineering (Florida, 2002). Such variation is concentrated regionally, with greater human capital focused more tightly around high-technology industries that tend to cluster spatially. Thus, Florida argued that the spatial variation of human capital is not random, depends on characteristics of a community, and may fluctuate with changes in that community, thereby differentially exposing students in different high schools to varying degrees and types of human capital. It therefore stands to reason that there is likely a relationship between high school context and students' enrollment in an engineering major—beyond specific resources that a particular high school might offer, the broader community culture may influence how students view certain majors like engineering.

Finally, we also know that high schools vary geographically in students' demographic compositions, and there is a broad literature linking demographic characteristics to major choice (e.g., Jacobs, 1986, 1995; Simpson, 2001; Thomas, 1985) and persistence in engineering (e.g., Lord, Ohland, Layton, & Camacho, 2019). It would be inappropriate, however, to assume that the demographic characteristics of students from different high schools drive this relationship; rather, as we investigate in this paper, other variables tied to the nonrandom assortment of students into high schools are likely at the root of this underrepresentation. For example, Rosenbaum (1995) examined the Gautreaux program, a residential program in which low-income Black individuals were randomly assigned to live in middle-income, predominantly White suburbs or low-income, predominantly Black urban areas. In this quasi-experimental study, Black individuals who moved to the suburbs were more likely to enroll in college and enter professional careers. Thus, where an individual lives, as opposed to specific demographic characteristics, influences future employment opportunities, educational attainment, and social interaction (Rosenbaum, 1995), and a student's life could be changed by moving to an environment that fosters different opportunities (Galster & Killen, 1995).

Although gender distribution does not vary geographically, the interaction between women students and parents' educational attainment does vary geographically. Both Ware, Steckler, and Leserman (1985) and Leppel, Williams, and Waldauer (2001) determined that when the educational attainment of parents is high, women are more likely to enter a science field. Prior research in engineering argues that for women, in particular, matriculation as opposed to retention is the driving representation issue (Ohland et al., 2008), and so we also explored how high school and community contexts may explain gender differences in initial engineering enrollment.

## 5 | DATA AND METHODS

### 5.1 | Data set and population

We drew population data from an eight cohort time window from the Virginia Longitudinal Data System (VLDS), an automated federated linkage system that delivers deidentified, individual-level data managed by several state agencies, including the Virginia Department of Education (DOE) and the State Council of Higher Education for Virginia (SCHEV) (see <https://vlvs.virginia.gov/> for additional information). Developed with funds from the U.S. Department of Education, state agency personnel review data research requests and then provide access to specific data tables tailored to those requests. Data for this specific study were approved by the Virginia DOE and SCHEV as well as the investigators' university Institutional Review Board.

The population data in our analysis include all students who (a) completed public high school in Virginia in the 2007–2014 academic years using the DOE Student Records data table and (b) were present in either the National Student Clearinghouse (NSC) or SCHEV Course Enrollment Table (2007–2017) to denote enrollment in a postsecondary institution ( $N = 685,429$  students). We use student-level data from the following databases: Student Records (collected by DOE), National Student Clearinghouse (NSC, linked by DOE), and Course Enrollment Table (managed by SCHEV). Like many administrative data sets across agencies, data are linked in VLDS by comparing several student-level variables collected across databases to form matches probabilistically. Because the SCHEV data table provides a comprehensive set of information about students' Virginia postsecondary enrollments but does not include students who attended postsecondary schools outside of Virginia, we used the NSC table to include students who attended a non-Virginia postsecondary institution or students who did not appear in the SCHEV table because of data quality issues.

Using the DOE Student Record table, we created three binary variables to characterize students' demographics. We recognize that demographic information is not necessarily static over time, but we elected to use the information reported during the academic year in which students completed high school. Table 1 displays the demographic characteristics of the population. Males and females nearly split the population of high school completers across Virginia over the period of record. Slightly more than one-third of high school completers were characterized as URM, and over one-quarter were characterized as economically disadvantaged during their twelfth grade year of high school.

### 5.2 | Postsecondary enrollment variables

This study focuses on the transition between high school and a four-year degree granting postsecondary institution, regardless of pathway (as we describe in more detail in the Limitations section). The *4-Year Enrollment* variable consists



Variable	Raw number	Percentage
Gender		
Male	342,223	49.9%
Female	343,206	50.1%
URM status <sup>a</sup>		
URM	239,487	34.9%
Non-URM	445,942	65.1%
Economic status <sup>b</sup>		
Economically disadvantaged	191,654	28.0%
Not economically disadvantaged	493,775	72.0%

**TABLE 1** Demographic characteristics (period of record: 2007–2014 HS completion)

Abbreviations: HS, high school; URM, underrepresented minority.

<sup>a</sup>Includes American Indian or Alaska Native, Black, Hispanic, Native Hawaiian or Pacific Islander, and Non-Hispanic two or more races.

<sup>b</sup>Eligible for free/reduced meals, receives Temporary Assistance for Needy Families (TANF), eligible for Medicaid, identified as migrant, or experienced homelessness.

Variable	Raw number	Percentage
Postsecondary status		
Four-year enrollment	326,979	47.7%
Did not attend four-year institution	358,450	52.3%
Engineering <sup>a</sup> enrollment status		
Engineering enrollment	25,079	3.7%
Did not enroll in engineering	660,350	96.3%

**TABLE 2** Postsecondary enrollment characteristics (2007–2014 HS completion)

Abbreviation: HS, high school.

<sup>a</sup>For the purposes of this study, “engineering” also encompasses computer science.

of students who enrolled in a four-year institution at any time following high school completion. For example, students could have matriculated directly from high school, taken a gap year and then matriculated, or transferred from a two-year institution. As shown in Table 2, just fewer than half of all high school completers in our period of record enrolled in a four-year institution.

To derive our primary postsecondary outcome variable of interest, *Engineering Enrollment*, we identified students who enrolled in a bachelor’s degree-granting engineering or computer science program (hereafter referred to as “engineering”) at any time at a four-year postsecondary institution. Classification of Instructional Programs (CIP) code information developed by the National Center for Education Statistics for students’ major in the SCHEV or NSC data sets guided this categorization. Of all high school completers from the eight cohorts in our period of record, approximately 25,000 students (3.7%) enrolled in an engineering major. This sample encompasses students who declared an engineering major at any time in their postsecondary careers, including those who matriculated directly into engineering from high school, transitioned from a different major (including general studies) into engineering, or who transitioned from a community college into a four-year engineering program.

### 5.3 | Analyses

We characterize enrollment in a four-year undergraduate engineering degree from high school of origin for students who completed public secondary school in Virginia. As argued by Loeb et al. (2017) in a report prepared for the Institute of Education Sciences, such descriptive analyses can be very powerful stand-alone research products to characterize socially important phenomena. To address our research questions, we conducted analyses primarily at the high school level ( $n = 322$ ). We focused on the high school as opposed to the school division (note: some states refer to this organizational unit as a school district) because our earlier research showed high within-division variability (Matusovich,

Gillen, Carrico, Knight, & Grohs, 2020) and research by Orr, Ramirez, Ohland, and Lundy-Wagner (2012) showed school-level variables to be better predictors than division-level variables for engineering persistence.

To address the first research question regarding geographic variation, we established baseline state averages across high schools for four-year enrollment rates (i.e., the *4-Year Enrollment* divided by the *high school completers* for each high school) as well as engineering enrollment rates (i.e., the total *Engineering Enrollment* divided by the *4-Year Enrollment* variables for each high school) for (a) male students, (b) female students, (c) URM students, and (d) economically disadvantaged students. Given the size of the data set, we also present summaries of two- and three-way intersectional descriptive analyses between these demographic variables (e.g., comparing high school averages of URM females to non-URM females). Next, we display results graphically through a series of maps; for each demographic group, we conducted mean splits and mapped schools according to engineering rate to visualize patterns.

We present these results on a base map that displays the community socioeconomic status (*community SES*) of each zip code. Drawing on data for each Virginia zip code from the 2016 American Community Survey, the community SES variable for each zip code was derived from the population of adults age 25 or above, number of adults with bachelor's degrees age 25 or above, and median income for 813 zip codes in Virginia with available data (note: data were not available for 83 zip codes). For each available zip code, we calculated the average percentile ranking for median household income and the share of adults with bachelor's degrees (see Mellnik & Morello, 2013). For example, if a zip code ranked at the 25th percentile for median household income and at the 75th percentile for share of adults with bachelor's degrees within Virginia, the community SES would be 50. Deriving an SES variable from community-level median income and educational attainment is consistent with Perna and Titus (2005). A reference map of this zip code data with landmarks can be found in the Appendix.

To examine the relationship between undergraduate engineering enrollment and characteristics of the high school and community contexts across Virginia's high schools (RQ2), we used step-wise multiple regression analyses to model the engineering enrollment rates for high schools as a function of the number of high school completers (i.e., a proxy for school size), the community SES (i.e., the derived SES value for each high school zip code), and the four-year college enrollment rate. We ran separate models for five different outcome variables of engineering enrollments across the high schools, including (a) all students, (b) males, (c) females, (d) URM students, and (e) economically disadvantaged students.

## 5.4 | Limitations

We acknowledge several limitations associated with this study design. First, although administrative data sets are powerful tools for providing insights on social phenomena, data quality is outside of researchers' control and relies on external stakeholders (i.e., state agencies, school division data reporting, postsecondary data reporting). With VLDS, data sets across agencies are linked via probabilistic matching, and mismatched cases can occur, albeit infrequently. We have done our due diligence in cleaning and checking for any systematic errors with the data (e.g., missing school divisions or differences in major enrollment processes or codes across postsecondary institutions) and worked with our state-level partners throughout the process to identify and fix problems prior to completing these analyses.

Second, we made decisions with respect to certain variables that should be considered as readers interpret results. In addition to the points raised in the Terminology section, demographic variables represent a single snapshot in time (e.g., economically disadvantaged status as reported in a student's twelfth grade year), yet we recognize that such demographic variables are not necessarily static. Given the size of the data set, we do not anticipate that such shifts in students' gender or URM status would have an appreciable influence on the results. Students' socioeconomic status, however, could change over time as a student's or their family's income situation changes. Michelmores and Dynarski (2017) demonstrated a cumulative effect such that stronger effects were observed for students classified as low income over multiple years. Students in our study may have been classified as economically disadvantaged at other points during high school, which could still influence their postsecondary pathways but would not be captured in our results. In addition, to calculate the four-year enrollment rate, we normalized across schools with the number of high school completers as the denominator. This decision could mask some of the disparities between schools in high school graduation rates. The limitation does not apply to the engineering enrollment variable since it was normalized using four-year enrollment.

Third, we acknowledge a limitation associated with the derivation of the community SES variable. Although students from multiple zip codes may attend a single high school, zip code boundary lines do not overlap with school zoning boundaries; moreover, many school divisions allow for some mobility across schools. Using the data associated

with the school's zip code in the calculation of that variable is our best approximation of the immediate community's SES.

Fourth, we chose to investigate enrollment in engineering, and not persistence, because we view those as different phenomena with different influences. Indeed, some of the influences on enrollment and persistence overlap, but extending our analysis past college matriculation was beyond the scope of this study. Our operationalization of enrollment was agnostic as to pathway—an individual who directly matriculated into engineering from high school was treated the same way as an individual who transferred into engineering after spending 2 years in another major, for example. Our approach sought to capture any student who enrolled in engineering at a four-year institution within the period of record, and, thus, students in the earlier cohorts do have longer to matriculate in a four-year institution than the later cohorts in this analysis. This approach recognizes the importance of community colleges as a pathway into engineering but does not separate out such pathways at this time, although that is an appropriate next step. Our future research will explore geographic differences between different pathways into engineering and whether enrollment rates or pathways have changed systematically over time. Our team also will explore other academic variables in future research with this data set, including, for example, students' access to and enrollment in high school mathematics courses.

## 6 | RESULTS

We organize findings into three subsections. First, we establish baseline averages of engineering enrollments across high schools for each demographic group (as well as intersections). Next, we compare each high school to state averages for each demographic group geographically across a series of maps to address the first research question. Finally, we present results of regression models that explore the relationships between average high school engineering enrollments and high school and community contextual variables to address the second research question.

### 6.1 | Baseline statewide averages in engineering enrollments

For all students across our study years of 2007–2017 (with high school completion by 2014), the average four-year enrollment rate across high schools was 43%, and of those students who attended a four-year institution, the average engineering enrollment rate across high schools was 6% (i.e., an unweighted average of the values from each high school). We observe different patterns across subpopulations in terms of average engineering enrollments across Virginia's public high schools (Table 3). The high school average for male engineering enrollment was 11.52%,

**TABLE 3** Intersections of demographic variables for four-year enrollment rate and engineering enrollment rate (of the four-year attendees)

Variable	Four-year enrollment rate	Engineering enrollment rate
Female	48.35%	2.34%
URM   non-URM	42.29%   51.16%	1.91%   2.59%
Economically disadvantaged   not	31.21%   55.42%	1.74%   2.53%
Male	38.34%	11.52%
URM   non-URM	33.64%   40.93%	8.71%   13.04%
Economically disadvantaged   not	23.53%   44.06%	9.11%   12.17%
URM	37.85%	4.93%
Economically disadvantaged   not	28.61%   46.36%	4.30%   5.13%
Economically disadvantaged	27.43%	4.79%
URM female   non-URM female	32.33%   30.87%	1.41%   2.23%
URM male   non-URM male	25.05%   23.22%	7.73%   11.46%

Abbreviation: URM, underrepresented minority.



compared to 2.34% for females, 4.93% for URM students, and 4.79% for economically disadvantaged students. These values serve as the statewide baselines on the maps that follow.

We first point out some key differences across demographic groups shown in Table 3. Despite having the highest four-year enrollment rate among the demographic groups (i.e., the four-year enrollment divided by the high school completers for each high school), females enrolled in engineering at the lowest rate. Smaller percentages of URM and economically disadvantaged high school completers enrolled in a four-year institution, yet across Virginia, students from these groups enrolled in engineering at more than twice the rate as females who attended four-year institutions. Indeed, URM and economically disadvantaged students are underrepresented in engineering bachelor's programs, but our results suggest that discrepancies in four-year college-going may be a larger determinant of differences in representation in engineering enrollment, which is a different determinant than for female students.

These subpopulations of students are not mutually exclusive, and we also present intersections across demographic variables in Table 3. In most cases, membership in multiple minoritized subgroups correspond with lower percentages of engineering enrollments. For example, URM females enrolled in engineering at lower rates than non-URM females, and so we see more severe underrepresentation with intersections of minoritizing constructs. The combination with the lowest representation among engineering enrollments was URM, female, and economically disadvantaged; across high schools, only 1.41% of such students who attended a four-year institution enrolled in engineering. One notable exception to the pattern is for non-URM, economically disadvantaged males; across high schools, this group enrolled in engineering at nearly the same rate (11.46%) as noneconomically disadvantaged males (12.17%). Thus, for males who attend a four-year institution, race/ethnicity is a greater discriminator than economically disadvantaged status for engineering enrollment.

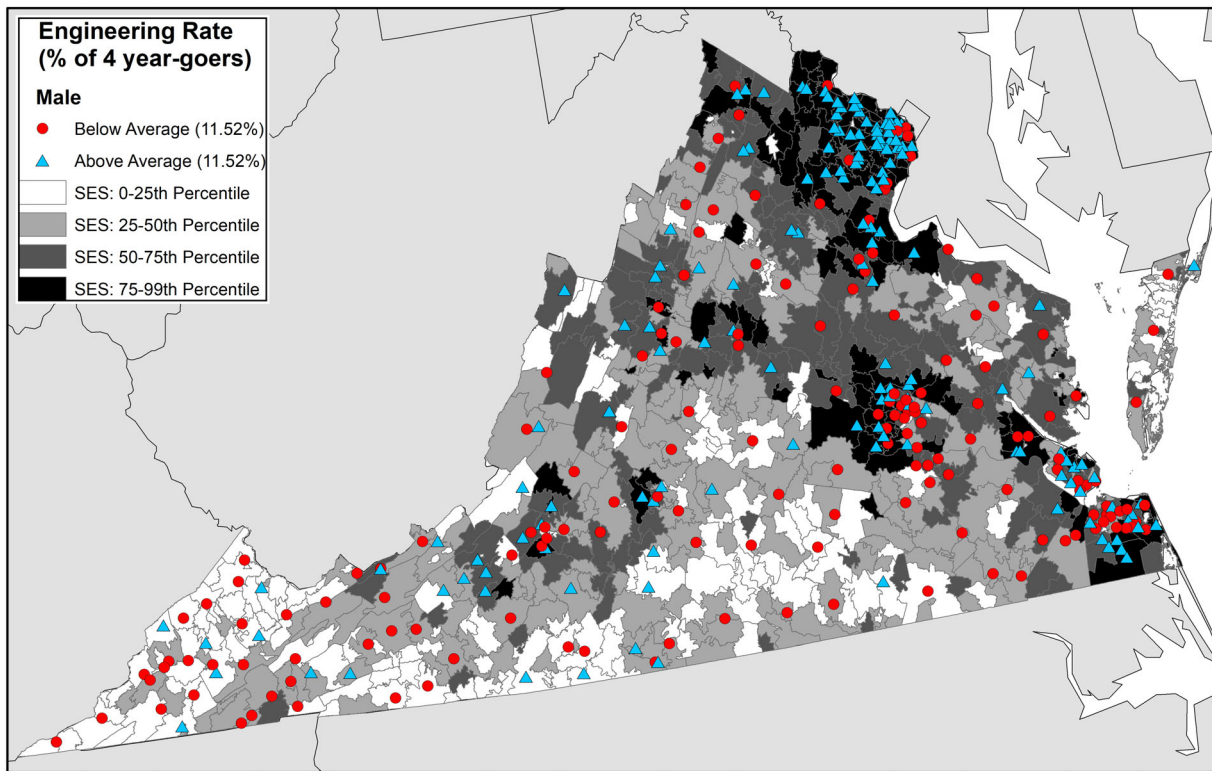
## 6.2 | Geographic variation in engineering enrollments

The Appendix orients readers to Virginia geographically and provides a base map of community SES for each zip code. We highlight three major regions that are the main population centers of Virginia. Northern Virginia, which includes the ever-expanding suburbs of the Washington, D.C., area, is the most populous region and has the greatest concentration of zip codes that fall within the upper quartile of community SES. As Florida (2002) would describe, it is the region that includes the highest STEM-related human capital. Southeastern Virginia has a large military presence with multiple bases across branches, is the site of a NASA research center, and has strong industry presence with multiple shipyards. As the map demonstrates, this region has substantial variation in zip code-level SES. Richmond is the state capital and is characterized by high SES zip codes in a suburban ring, particularly to the west of the city, with lower SES areas within the city. The population tends to be more scattered across the rest of Virginia, and zip code-level SES generally falls below the state median. Southern and southwestern Virginia, in particular, are rural and tend to contain zip codes at the lowest end of the SES continuum. Exceptions to this pattern for regions outside of the main population centers typically are found in areas with a four-year university, which are noted on the map. Thus, this map visualizes how Virginia systematically varies geographically in its community contexts.

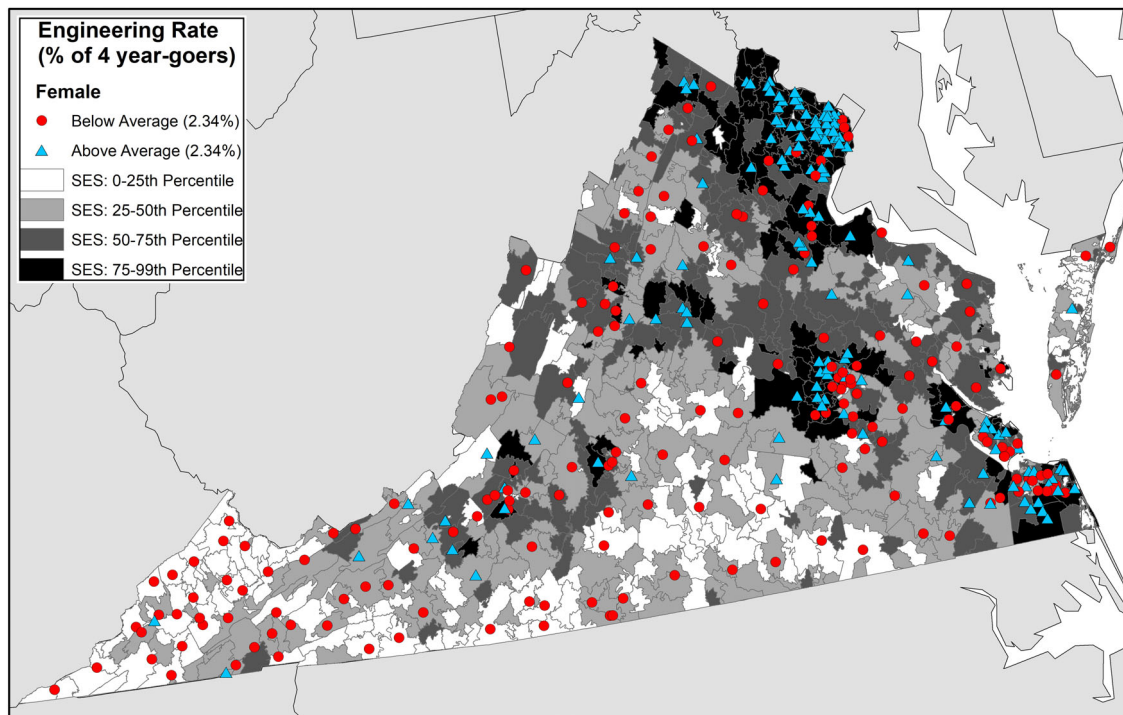
To address the first research question regarding geographic variation, we overlay engineering enrollment rates for each high school relative to the baseline state averages (from Table 3) to visualize geographic patterns in engineering enrollment rates (note: no schools fell exactly on the mean). We do not display intersections of these variables on maps because the numbers of students are too small at the individual high school level. Figure 1 shows geographic patterns in engineering enrollment rates across high schools for males, Figure 2 for females, Figure 3 for URM students, and Figure 4 for economically disadvantaged students.

The four maps depict a few similar geographic patterns across each demographic group. We note that high schools above the state average and high schools below the state average in engineering enrollment rates are present in all regions of Virginia. Although we generally see a positive association between community SES and engineering enrollment rates (i.e., the above-average schools are typically located in the darker shaded areas of the map and vice versa, which we test in the subsequent regression analysis), we do see some counter examples. There are schools with above-average engineering enrollment rates in lower SES areas (lighter shadings) and schools with below-average engineering enrollment rates in higher SES areas (darker shadings).

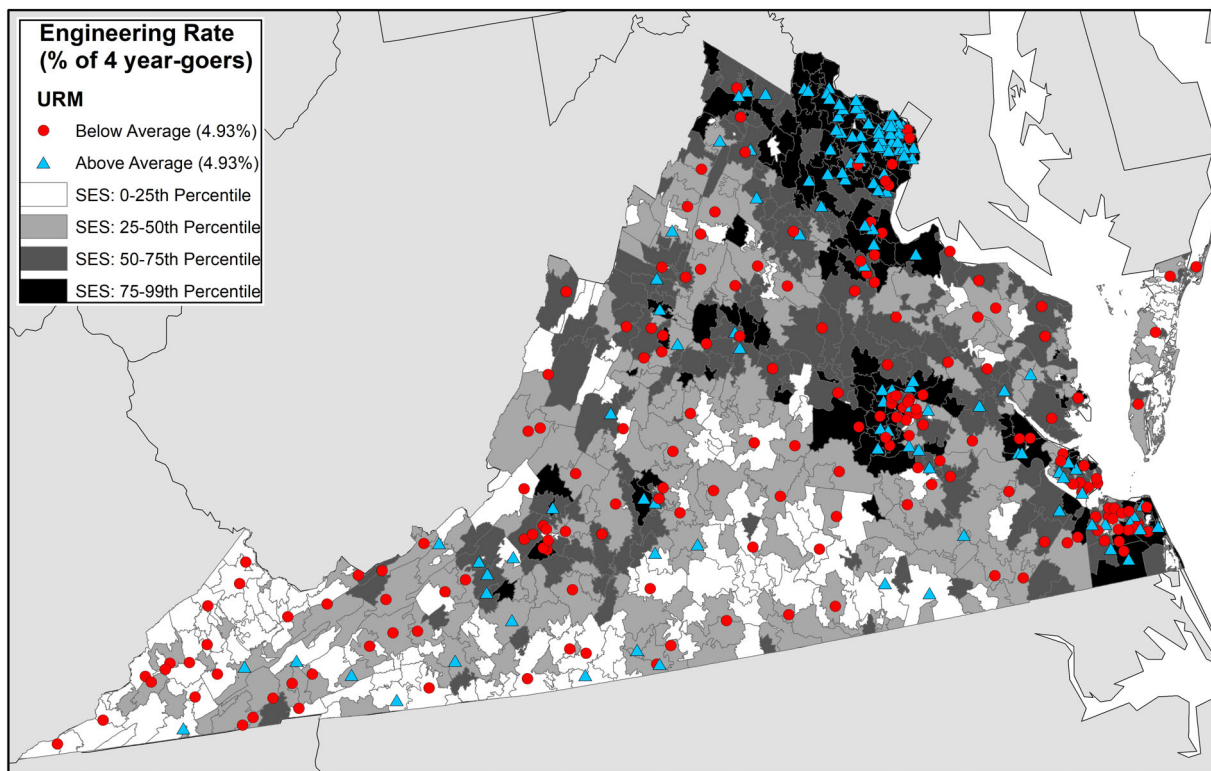
In addition, we note a preponderance of above-average engineering enrollment rate high schools in certain regions, such as northern Virginia, and that pattern is consistent across demographic groups—as depicted by all four maps showing high concentration of blue triangles in this region. As we previously described, this region would be



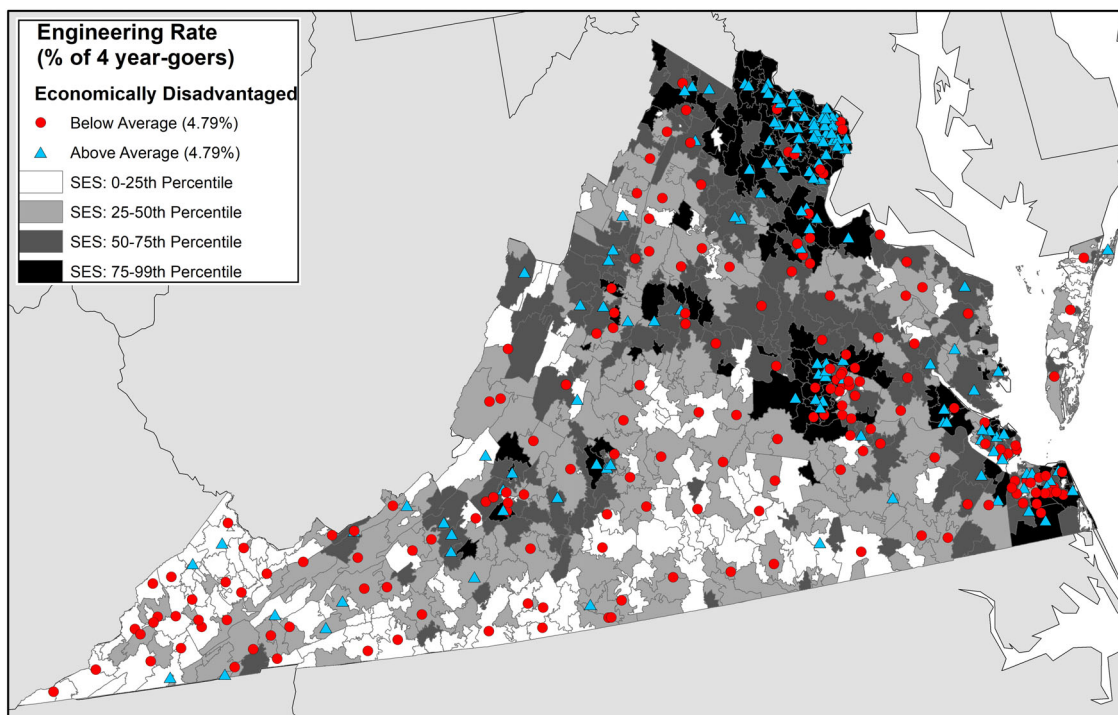
**FIGURE 1** Engineering enrollment rates by high schools for male students (i.e., percentage of male students from each high school who attend a four-year institution and enroll in engineering). Red circles represent schools below the state average, and blue triangles represent schools above the state average. The base map represents zip code-level socioeconomic status on a percentile basis [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]



**FIGURE 2** Engineering enrollment rates by high schools for female students (i.e., percentage of female students from each high school who attend a four-year institution and enroll in engineering). Red circles represent schools below the state average, and blue triangles represent schools above the state average. The base map represents zip code-level socioeconomic status on a percentile basis [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]



**FIGURE 3** Engineering enrollment rates by high schools for URM students (i.e., percentage of URM students from each high school who attend a four-year institution and enroll in engineering). Red circles represent schools below the state average, and blue triangles represent schools above the state average. The base map represents zip code-level socioeconomic status on a percentile basis. URM, underrepresented minority [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]



**FIGURE 4** Engineering enrollment rates by high schools for economically disadvantaged students (i.e., percentage of economically disadvantaged students from each high school who attend a four-year institution and enroll in engineering). Red circles represent schools below the state average, and blue triangles represent schools above the state average. The base map represents zip code-level socioeconomic status on a percentile basis [Color figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]



characterized by Florida (2002) as containing the highest STEM-related human capital in Virginia. In contrast, in southwestern and south-central Virginia, which contain more rural regions and lighter shadings of the community SES variable, schools tend to send students into engineering at below-average rates. We also observe several geographic regions with above- and below-average engineering enrollment high schools immediately adjacent to one another. For example, we see that pattern across each of the four maps for the southeastern Virginia and Richmond regions. As we noted in our opening description of Virginia, there is notable geographic variation in community SES in these regions.

Finally, although some individual schools switch signs across the four maps (i.e., from above- to below-average, and vice versa), the overall geographic pattern across Virginia is fairly similar across demographic groups. That is, schools that enroll above-average percentages of males in engineering also tend to enroll above-average percentages of females, URM students, and economically disadvantaged students in engineering (with the reverse true as well). The geographical differences by high schools appears to transcend demographic groups. One notable exception to this pattern can be seen in Figure 1: for male engineering enrollments in the south-central and southwestern areas, we observe more above-average blue triangles in those regions on this map relative to the maps for the other demographic groups.

### 6.3 | Relationship between engineering enrollments and high school contextual variables

Whereas the series of maps visualize systematic patterns in engineering enrollment rates as a function of a high school's location, our next set of analyses further interrogated those patterns and explored high school engineering enrollment rates for each demographic group as a function of the number of high school completers (i.e., school size), community SES, and four-year enrollment rate from each high school. Table 4 displays the standardized coefficients for each stepwise regression model. Each of these models met assumptions for regression analyses, and multicollinearity between variables was acceptable (i.e., all VIFs below 5). We gain significant information with the inclusion of each high school and community context variable as the adjusted  $R^2$  values increased in each model. For the full models, adjusted  $R^2$  values ranged from .31 (male engineering enrollment) to .50 (female engineering enrollment).

The four-year college enrollment rate was the strongest predictor of engineering enrollment rate by about a factor of two across all models, with community SES as the second strongest predictor. Thus, when a higher percentage of a high school's graduating class attends a four-year institution, a greater proportion of those students who attend a four-year institution will enroll in engineering. Taking into account four-year college enrollment rate and community SES, the number of high school completers no longer contributed unique variance to these predictive models for all engineers, males, and economically disadvantaged students but continued to contribute, although weakly, to models predicting engineering enrollment for female and URM students. The engineering enrollment rate was higher for females and URM students in larger high schools relative to smaller high schools.

**TABLE 4** Standardized coefficients of regression models for engineering enrollment across high schools ( $n = 322$ ) for different student subpopulations as a function of high school and community contextual variables

	All			Male			Female			URM			Econ Disad		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Number of HS completers	.49**	.15*	.10	.36**	.09	.04	.54**	.29**	.18**	.43**	.17**	.13*	.35**	.04	-.01
Community SES		.53**	.23**		.42**	.16*		.48**	.21**		.41**	.18*		.48**	.22**
HS four-year enrollment rate			.46**			.41**			.42**			.35**			.39**
Adjusted $R^2$	.24	.39	.49	.13	.23	.31	.29	.42	.50	.18	.27	.33	.12	.25	.32

Abbreviations: Econ Disad, economically disadvantaged; HS, high school; SES, socioeconomic status; URM, underrepresented minority.

\* $p < .05$  \*\* $p < .01$ .

## 7 | DISCUSSION AND IMPLICATIONS

Perna's (2006) literature synthesis showing the importance of school and community contexts for postsecondary choices guided our analyses conceptually. Our results support this framing for enrollments in postsecondary engineering; we show distinct connections between students' high school of attendance and engineering enrollment rates at four-year institutions. The series of maps demonstrate systematic patterns in engineering enrollments that would not be apparent if not displayed visually. Engineering education has a long history of displaying data using tables and plots, but mapping the geographic element can help us understand engineering pathways from a different perspective. Such visual representation can help direct future geography-grounded research following more systematic and/or explanatory methods. Making geographic connections between academic major choice and high school and community context has not received much focus in prior research (Goyette & Mullen, 2006).

### 7.1 | Differences for minoritized students

In deriving state-level baselines for each demographic group, several observations merit discussion. First, we show substantial gender discrepancies with respect to students enrolling in engineering. Often we see figures showing that females comprise approximately only one-fifth of engineering bachelor's degrees awarded (National Science Board, 2018). At the same time we know there is a gap for women enrolling in engineering programs, but our comparison to enrollment in four-year programs for an entire state shows how astounding this gap really is. Despite a higher percentage of females than males entering a four-year institution across Virginia, only 2.34% of females enrolled in engineering, a rate five times less than males (at 11.52%). Thus, our data join prior studies showing that the act of selecting the major is a bellwether for gender disparities in bachelor's degrees and in the workforce—although what happens in college and beyond is also important, the gap is already established at matriculation.

The presence of the enrollment gap is not as surprising as the magnitude of the gap. The gap itself is potentially explained by gender socialization toward careers, which research shows happens early and broadly. Specifically with regard to engineering, the messages young women receive about engineering do not align with what motivates them with regard to academics and careers. According to research from a national study, young women want to enjoy their work, have a good working environment, make a difference, earn a good income, and have flexibility in their jobs. The messages they hear, however, describe engineering as a challenging career, that it is difficult but rewarding, and that it uses math and science to solve problems, and these messages may feel at odds with their imagined futures (Extraordinary Women Engineers Project, 2005). Moreover, the recent societal discussions about the persistence and prevalence of gender-based harassment and discrimination, particularly in STEM fields (National Academies of Sciences, Engineering, and Medicine, 2018), may further discourage young women from seeing themselves as successful in and desiring engineering careers. Although we are also exploring practices for high schools that send greater-than-expected numbers of females into engineering, we hope that the broader current context of the #MeToo movement will force needed messaging and workplace changes (e.g., Jagsi, 2018). There are known, systemic and structural problems in the STEM workplace environment regarding harassment and discrimination that need to change (e.g., National Academies of Sciences, Engineering, and Medicine, 2018).

We also found that URM and economically disadvantaged males enrolled in engineering at more than double the rate of female students. For those student groups, the bigger indicator for underrepresentation in engineering relates to four-year college enrollment. This finding is consistent with the broader literature on the relationship between educational attainment and race/ethnicity and socioeconomic status (Paulsen & St. John, 2002; St. John & Asker, 2001). Because of the scope and comprehensiveness of our data set, we were able to parse these differences more precisely than other studies because we could consider intersections of underrepresented demographic variables. For the most part, consistent with the literature (e.g., Lord et al., 2009), there appear to be additional "penalties" or barriers imposed by the system for each additional underrepresented attribute with respect to enrollment in engineering, and the combined effect is evident in these data—females enroll at lower rates than males, URM females enroll at even lower rates, and URM, economically disadvantaged females enroll at the lowest rates.

Importantly, we identified an instance where intersections of demographic attributes did not coincide with lower rates of engineering enrollment. Non-URM, economically disadvantaged males enrolled in engineering at a similar rate to the nonminoritized group. We wonder if the system and its messaging about engineering as a career effectively resonates with economically disadvantaged non-URM males, in particular, and they see an engineering career as a path toward social mobility. Prior research by Ma (2009) using the National Educational Longitudinal Study of 1988



suggested that socioeconomically disadvantaged students tend to select majors with stronger job prospects, like those in the technical fields, when they controlled for precollege variables. Similarly, Davies and Guppy (1997) argued that social mobility and longer-term economic security were important considerations for students from socioeconomically disadvantaged families as they made decisions about higher education. Future research should focus on this group in particular to determine why—and how—non-URM economically disadvantaged males seem to behave differently with respect to engineering enrollment than would be expected.

## 7.2 | Geographic differences in engineering enrollments

In looking across the maps (Figures 1–4), the overall geographic patterns appear to be fairly consistent across different demographics, with a few notable exceptions. That is, high schools that tend to enroll males at above-average rates also tend to enroll URM students and economically disadvantaged students at above-average rates. This finding is consistent with Rosenbaum's (1995) study that sought to disentangle an individual's race from their surrounding environment in terms of college and career outcomes. Similar to that prior study, our results suggest that where minoritized individuals attend high school, as opposed to their individual demographic characteristics, influences their engineering enrollment. Schools with access to sufficiently resourced teachers, counselors, and peers provide prospective college students opportunities for information related to college (Perna, 2006). In addition to personnel, Klugman (2012) and Rowan-Kenyon, Perna, and Swan (2011) concluded that programmatic and nonprogrammatic resources found in high schools influence postsecondary decisions and can mediate the effect of individual family SES on postsecondary choice. Thus, resources at the high school level can have an important effect on postsecondary pathways. In Virginia, as in many other states, there is a nonrandom distribution of URM and economically disadvantaged students across high schools, and high schools with greater concentrations of these minoritized students tend to be under-resourced. We believe our findings support the notion that racially minoritized and economically disadvantaged students are systematically excluded from engineering because of how students are distributed across high schools geographically; as Lee (2019) would describe, such students are enacted upon by a surrounding system with little agency to be able to change their course. We believe changing these systematic inequities requires a rethinking of resource allocation across the K-12 sector.

The spatial results also demonstrate that there are schools in all regions of Virginia that buck the trend, sending above- or below-average rates of students into engineering, with some areas having adjacent schools displaying opposite patterns. This observation suggests that large-scale geography (e.g., rural versus suburban versus urban) may not provide the level of precision required to understand engineering pathways. Consistent with research by Orr et al. (2012) using the MIDFIELD database showing that school-level variables were better predictors of engineering persistence than division-level variables, our research shows that a similar level of analysis might be important for investigating patterns between high school and postsecondary engineering enrollment. Our ongoing research aims to understand why high schools with similar characteristics in similar locations have different engineering enrollment rates.

Despite exceptions in each region, we do see a greater preponderance of above-average engineering enrollment rates from high schools in northern Virginia and below-average engineering enrollment rates from high schools in southwestern and south-central Virginia. These results are consistent with Florida's (2002) economic geography research, which showed strong connections between the geography of his derived measure of STEM-related human capital and location of high-technology industries and regional incomes. Since we observed similar geographic relationships for engineering enrollments, our results have implications for states as they consider attracting new industries in a bit of a chicken-or-egg scenario. Do new high-tech industries need to be recruited to existing regions with such human capital to attract a workforce, which our maps would suggest could continue growing that region's engineering enrollment rates? Or, could new high-tech industries be recruited to adjacent regions in an effort to expand such human capital through a new workforce, which over time could grow that region's engineering enrollment rates? Our data cannot speak to the answer, but some of the large-scale regional patterns shown in the maps can help us think about implications of different scenarios.

## 7.3 | Engineering enrollments and high school contextual differences

Regression models exploring the relationship between engineering enrollment rates as a function of school size (operationalized as number of completers), community SES, and the high school's four-year college enrollment rates

were surprisingly strong predictors, especially since we did not incorporate any more specific information about the individual students enrolled in each school. As we noted in the literature review, the relationship between school size and outcomes is varied and complex, and to our knowledge, our study is a first for using major choice as the outcome variable. One consistency in the literature especially pertinent to engineering-going was with respect to larger schools being able to offer more academically advanced courses (Lee et al., 2000) and being able to staff more AP Calculus teachers (Schreiber, 2002). Given our findings that the relationship with school size is no longer significant when accounting for community and four-year enrollment rates for most models, we push back on the notion that larger schools can offer more STEM experiences and, therefore, graduate more students who will pursue engineering in college. Our finding joins a recent study based in Missouri using a longitudinal data system that found that postsecondary STEM enrollment was not influenced by differential access to courses across high schools (Darolia, Koedel, Main, Ndashimye, & Yan, 2018).

The model for female engineering enrollment displayed the strongest effect for school size (operationalized as number of completers) when accounting for the other high school and community context variables. Virginia's smaller high schools tend to be located in more rural regions, and although representation of women in these rural regions does not look different from urban or suburban areas, the interaction between women students and parents' educational attainment does vary geographically. The positive relationship with school size for women is likely driven by this larger regional difference as women whose parents' educational attainment is high are more likely to enter a STEM field (Leppel et al., 2001; Ware et al., 1985). An additional factor for women in rural areas may be linked to the strong tie of cultural messaging, in particular of traditional gender stereotyped careers (e.g., Wright, 2012). This factor may also interact with our previous finding related to gendered socialization of students.

We also derived a variable to characterize the surrounding community's average income and educational attainment in our models of engineering enrollment and found a moderate positive relationship across all demographic groups. This finding joins other studies showing a relationship between a community's SES and postsecondary educational outcomes (e.g., Carrico & Matusovich, 2016; Lundy-Wagner et al., 2014), albeit for a new statewide context in engineering specifically. A surprising finding, however, was the strongest relationship between a high school's four-year enrollment rate and its engineering enrollment rate. When schools send a higher percentage of its graduates to a four-year institution, a larger portion of those students enroll in engineering. There are a few potential explanations for this finding and some important implications to consider. First, as we have shown in case studies of different Virginia regions, schools differentiate, even within the same school division, in terms of school-wide messaging around postsecondary goals (Matusovich et al., 2020). Some schools focus on preparing students for a pathway of work right after high school; others focus on preparation for *any* postsecondary educational path, and still others focus on preparation for four-year institutions. This latter group comes with more specific career path coaching and resources, and students who attend such high schools may receive more messaging around engineering specifically.

Second, this finding may represent an interaction with one of our previous findings. As we noted in the literature review, the physical distance between some rural communities and four-year postsecondary institutions creates an access issue (Byun et al., 2015). Since rural communities tend to have a lower proportion of their graduates attend a four-year institution, the relationship between a high school's four-year enrollment and engineering enrollment may be driven, in part, by the differential distribution of STEM-related human capital in rural regions (Florida, 2002), a situation which has implications for how students, in particular female students, select STEM majors. Third, in high schools with higher percentages of students attending four-year institutions, we could be observing peer effects, which have been shown to influence science and engineering major choices (Legewie & DiPrete, 2014).

These findings have implications for broadening participation in engineering that are likely applicable for most states. The community SES relationship is a challenging one to change. State policymakers could work to adjust K-12 funding formulas or spur economic development in regions that tend to be under-resourced. Our findings also could push organizers of engineering outreach programs to consider how they might maximize their investments of limited funding through targeted programing on a geographic basis as well as how they partner with communities to develop outreach programs. They could focus on schools that have high four-year enrollment rates but low engineering enrollment rates as our models suggest these schools would be most ripe for change; some targeted outreach could make a big difference for engineering pathways. Alternatively, outreach programs could target schools from low-SES communities that do not have a strong four-year college enrollment history as a way to focus on reducing inequities in resource

access, which first might spur four-year college enrollments and, in turn, engineering enrollments. Importantly, the content of the outreach must also be considered carefully. “One-size fits all” and “hero” models of outreach do not account for the localized complexities that our research illuminates. Partnering with communities to develop culturally relevant engineering-related activities (e.g., Gillen, Carrico, Grohs, & Matusovich, 2018) could be a fruitful approach that is consistent with valuing the knowledge and skills different subpopulations bring to engineering (e.g., Wilson-Lopez, Mejia, Hasbun, & Kasun, 2016). Importantly, our findings for non-URM, economically disadvantaged males suggest there could be a path for breaking the system of expectations; learning more about that subpopulation could uncover new ideas.

## 8 | CONCLUSION

We took a macroscopic, systems view of one state’s population of high school to postsecondary students to understand variation in how graduating students enroll in engineering across each public high school. Our findings illuminate inequality in enrollment in engineering programs at four-year institutions across high schools by gender, race, and socioeconomic status (and the intersections among those demographics) as well as high school and community context. Where one attends high school makes a difference for engineering enrollments, and we see fairly consistent patterns geographically—albeit at different magnitudes—for different demographics. Our findings support the notion that racially minoritized and economically disadvantaged students have more systematic barriers to access because they disproportionately attend high schools with lower four-year college-going rates and live in lower resourced communities—and not because of any individual demographic characteristic. Schools that enroll male students at above-average rates tend to enroll female, URM, and economically disadvantaged students at above-average rates (and vice versa). Changing these systematic inequities likely will require a rethinking of resource allocation across the K-12 sector.

We also demonstrate that a high school’s four-year enrollment rate is a stronger predictor of that school’s engineering enrollment rate relative to community SES and school size. This finding further supports our assertion that strong systemic forces need to be overcome to broaden participation in engineering. We offer some ideas for state-level policies and university outreach practices stemming from this finding so that broadening participation in engineering has a better chance of occurring.

Finally, we demonstrate the powerful insights that state longitudinal data systems can illuminate in engineering education research. These data sets can help us interrogate systemic questions related to broadening participation comprehensively and in new ways, and our study could be replicated in other contexts with state-level data. Although we believe these large-scale findings would likely generalize to other states, that assumption could be tested empirically using other state longitudinal data systems. However, we also caution readers that large-scale analyses can lead to unwise policy decisions because observed patterns do not “explain” mechanisms. To unpack these aggregate analyses, our team is investigating strategically selected, adjacent schools that are above- and below-average for engineering enrollments, especially for underrepresented populations, to understand the structure and processes of school cultures that may be implicated in college major choice.

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## APPENDIX

Base map representing zip code-level socioeconomic status on a percentile basis. This map includes landmarks for reference points. The postsecondary institutions have the six largest enrollments of engineering students from Virginia's high schools.

