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RESEARCH ARTICLE

The fallacy of "there are no candidates": Institutional pathways of Black/African American and Hispanic/Latino doctorate earners

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Abstract

Background: Despite many initiatives to improve graduate student and faculty diversity in engineering, there has been little or no change in the percentage of people from racially minoritized backgrounds in either of these groups.

Purpose/Hypothesis: The purpose of this paper is to counter the scarcity fallacy, in which institutions blame the "shortage" of qualified people from traditionally marginalized backgrounds for their own lack of representation, related to prospective PhD students and prospective faculty from traditionally marginalized groups. This study identifies the BS-to-PhD and PhD-to-tenure-track-faculty institutional pathways of Black/African American and Hispanic/Latino engineering doctorate recipients.

Design/Method: Using the US Survey of Earned Doctorates, we tracked the BS-to-PhD institutional pathways of 3952 Black/African American and 5732 Hispanic/Latino engineering PhD graduates. We also used the Survey of Doctorate Recipients to track the PhD-to-tenure-track faculty pathways of 104 Black/African American and 211 Hispanic/Latino faculty.

Results: The majority of Black/African American and Hispanic/Latino PhD graduates in this study did not earn their BS degrees from Top 25 institutions, but rather from Not Top 25, non-US, and minority-serving institutions. The results also show the relatively small proportion of PhD earners and faculty members who move into highly ranked institutions after earning a bachelor's degree from outside this set of institutions.

Conclusions: The findings of this study have important implications for graduate student and faculty recruitment by illustrating that recruitment from a narrow range of institutions (i.e., Top 25 institutions) is unlikely to result in increased diversity among racially minoritized PhDs and faculty in engineering.

KEYWORDS
diversity, faculty, graduate education, pathways, recruitment

1 | INTRODUCTION

Underrepresentation of traditionally marginalized groups (e.g., Black/African American, Hispanic/Latino, American Indian, and Native Hawaiian/Pacific Islander) has been a persistent issue in engineering and computing (Slaton, 2010; Varma, 2018). The historical and social context that led to such a marginal proportion of these racial/ethnic groups across all of higher education cannot be understated (Parsons, 2014). The US education system has expanded for decades, yet since the inception of modern-day mass education, certain groups have been purposefully excluded from participation based solely on their racial/ethnic heritage (Parsons, 2014; Slaton, 2010). We are still living in the wake of those practices today. Moreover, despite increased opportunity to access higher education in the United States, the higher education system is still far from equitable.

This paper is not a retelling of the historical events (e.g., slavery, denial of citizenship, underfunded schools, denial of access to post-secondary education, racialized violence, forced migration, depravation of culture, and language assimilation) that led to the present state of representation within higher education broadly and within engineering more specifically. Yet we would be remiss not to remind readers that the numerical representation of racial/ethnic groups in US higher education is very much situated in past and present systems and structures that act as obstacles to terminal degree attainment (McGee, 2020, 2021; Parsons, 2014). Historical events also contribute significantly to the resources, power, and prestige—or lack thereof—of any academic institution and the advantages afforded to certain institutions (namely, primarily White institutions) and demographic groups. As we will discuss, these inequities have tremendous ramifications for the people who enroll and work at these institutions, particularly those who seek to move between institutions with different levels of power and prestige.

The purpose of this paper is to counter what we refer to as the "scarcity fallacy" related to prospective PhD students and prospective faculty from traditionally marginalized groups by highlighting the relatively small proportion of PhD earners and faculty members who move into highly ranked institutions after earning a bachelor's degree from outside these institutions. We focus on the scarcity fallacy because the rhetoric of scarcity, wherein institutions blame their lack of faculty diversity on the "shortage" of qualified people from traditionally marginalized groups, has occupied disproportionate space in the conversations about broadening participation at the faculty level. With the present analysis, we illustrate why this scarcity is a fallacy borne of a narrow definition of qualified candidates. This scarcity mindset can be directly related to the tendency to conceptualize participation in engineering as a pipeline. As Lee (2019) notes, viewing the broadening participation challenge through this lens enables institutions to redirect blame to previous parts of the system. We instead apply what Lee refers to as the pathway paradigm to shed light on the role the institutions themselves are playing in creating the results we see today, which is similar to a prior analytical approach taken by Lord et al. (2019) to focus on migration between engineering disciplines at the undergraduate level.

We focus the current study on institutional pathways across academic levels. By institutional pathways, we are referring to the types of institutions students earn credentials from along the BS-to-PhD and PhD-to-tenure-track (TT) faculty trajectory. We center our analysis on doctorate earners because the PhD is a prerequisite to most faculty positions, and the dominance of White men is particularly prominent among engineering faculty, who serve as gatekeepers to the profession. This White male dominance is concerning because it limits the diversity of people and ideas that can flourish in engineering. Research shows that there are many benefits to having a diverse faculty. African American engineering and computer science undergraduate students at primarily White institutions (PWIs) commented on the need for same-race faculty mentors, explaining that such mentors would be able to better relate to students' challenges and help them better envision themselves as successful in their field (Newman, 2015). STEM and business undergraduate students, graduate students, and postdoctoral scholars said it was "somewhat important" to have a same-race or -gender mentor, and those with the same race or gender as their mentor reported receiving more help (though shared mentor–mentee demographics did not affect academic outcomes, Blake-Beard et al., 2011). Researcher identity also plays a role in decision-making within the scientific process, including, for example, which research questions to pursue, how results are interpreted, and how findings are disseminated; a more diverse faculty will pursue more diverse research ideas (Leggon, 2010). Additionally, a correlation has been shown at the department level between the number of engineering BS degrees earned by women of color and the number of faculty who are women of color (Main et al., 2020).

Unfortunately, as of 2019, Black/African American and Hispanic/Latino tenure-track faculty represented only 2.5% and 3.7% of all tenure-track engineering faculty, respectively (Roy, 2019). This represents a 0% increase in each group as compared with 2011, and a 0.6% and 1.4% decrease in percentage from each group, respectively, from its peak in 2017 (Roy, 2019). Although these statistics are a useful and sobering snapshot of the demographics of tenure-track faculty, they fail to capture the pathways of individuals who comprise them. Accordingly, in this paper, we consider the institutional pathways of these individuals, both during their education (BS-to-PhD) and academic careers (PhD-to-tenure-track faculty).

Given the differing experiences of people within these groups, it is important to investigate specific races individually and uncover patterns and trends about mobility between institutions of different rankings and types, including minority-serving institutions (MSIs). Unfortunately, at the institutional level, there is a tendency to aggregate underrepresented groups together because of small numbers. In this paper, we use a large, national-scale data set to address the following research questions:

1. What are the institutional pathways to a PhD for Black/African American and Hispanic/Latino engineering and computer science doctorate earners?
2. What are the institutional pathways to a tenure-track faculty position for Black/African American and Hispanic/Latino engineering and computer science PhDs?

In addition to institutional pathways, we also explore how prestige can affect these pathways. Not only do more prestigious institutions have more resources for conducting research and building one's portfolio, attending such an institution appears to also add invisible "points" to a scientist's record (Way et al., 2019). Conceptions of "qualified" or "highly ranked" applicants favor those who attend more prestigious institutions, influencing opportunities within graduate school and, later, at the faculty level (Burris, 2004; Clauset et al., 2015; Posselt & Grodsky, 2017). Critical scholar Daniel Solórzano posed the question: what is the cumulative effect of less-prestigious undergraduate and graduate institution types on Black students' later career opportunities? (Solórzano, 1995). We explore the answer to this question, both for Black/African American doctorate earners and for Hispanic/Latino doctorate earners in engineering and computer science.

1.1 | Note on terminology

The National Science Foundation (NSF)-administered surveys phrased the race/ethnicity questions using the terms "Black or African American" and "Hispanic or Latino" (National Center for Science and Engineering Statistics [NCSES], 2021b). However, we recognize that there are differences within these groups, and individuals have their own preferences for how they self-identify. A weakness of the term "African American" is that it does not encompass individuals with Caribbean or Afro-Caribbean ancestral roots, whereas "Black" does (Agyemang et al., 2005). One study found that people's preference for the term "Black" versus "African American" depended on factors including age and region of the United States, although preferences fluctuate over time (Sigelman et al., 2005). In recent education literature, "Black" and "African American" have been used interchangeably (Strayhorn, 2020).

"Hispanic" includes people of Spanish-speaking origin, but does not include non-Spanish-speaking people from Latin America. "Latino" does include people from Latin America and can be seen as more accurately describing a group of people whose countries have a shared history of colonialization (Martin Alcoff, 2005). More recently, "Latinx" has emerged as a gender-neutral version of "Latino"; however, 75% of Latinos have not heard of this term, and only 3% (mostly Latina young women) actually use it (Noe-Bustamante et al., 2020).

We acknowledge the histories and subtleties of these terms, but we use "Black/African American" and "Hispanic/Latino" in this paper because those are the terms to which participants responded on the surveys administered by the NSF; for referenced articles, we use the terminology in the original article.

2 | LITERATURE REVIEW

2.1 | Defining HBCUs and HSIs

MSIs have been a critical pathway for underrepresented minorities' (URM) attainment of degrees in STEM, both at the undergraduate and graduate levels. URM is an acronym commonly used by the US government and academic institutions to encompass several racial/ethnic groups, including Black/African Americans, Hispanics/Latinos, and American Indian/Alaskan Natives. We recognize that MSI types include Historically Black College and Universities (HBCUs), Hispanic-Serving Institutions (HSIs), Tribal College or Universities (TCUs), Native American Serving Non-Tribal Institutions (NASNTIs), Predominately Black Institutions (PBIs), and Alaska Native and Native Hawaiian Serving Institutions (ANNHs). The focus of this study is on HBCUs and HSIs because of sample size concerns and reporting restrictions tied to the restricted-use data sets that precluded our reporting results for other types of MSIs (US Department of Education, 2021).

HBCUs were founded starting in the late 1830s, with the primary mission of serving the African American community. As we write these words, there are 101 federally recognized HBCUs located in the United States and US Virgin Islands. These institutions are located mostly in the southern United States and are often founded with the assistance of religious missionaries from the northern United States (Albritton, 2012). The Higher Education Act of 1965 officially bestowed the designation of HBCU upon any historical Black college or university founded before 1964 with a mission to educate Black Americans. Although these institutions were the main locations of higher learning for Black Americans prior to desegregation, diversification in the choice of Black students and online education has led to declining enrollments at HBCUs, which has been exacerbated by the already small endowments and financial struggles that HBCUs face in serving their student populations (Johnson, 2017). Nevertheless, HBCUs are still a critical pathway for Black students' success in higher education (Burrelli & Rapoport, 2008; Solórzano, 1995), as these institutions are noted for providing nurturing, community-oriented and student-focused environments for Black students to gain academic confidence and succeed (Gewin & Payne, 2021; Johnson, 2017).

Unlike HBCUs, Hispanic-serving institutions were not created explicitly to serve as postsecondary pathways for Hispanic communities, a recent focus has been on defining "servingness" among HSIs (Garcia, Ramirez, et al., 2019). Rather, to become an HSI, there are two requirements: be an eligible institution (according to the US Department of Education) and have at least 25% of enrolled undergraduate students identify as Hispanic (US Department of Education, 2018). With few exceptions, HSIs generally do not have a charter or mission to address the purposes and goals of Latinos. However, these institutions have risen to serve in this capacity with the growing proportional representation of Hispanics entering higher education. The goal has been supported by organizations such as the 1986 formation of the Hispanic Association of Colleges and Universities (HACU), which connects HSIs and advocates for educational policies. Enrollment at HSIs and the establishment of emerging HSIs are expected to continue to increase as the Hispanic/Latino population in the United States grows. As of 2020, there are 569 HSIs and 362 emerging HSIs in the United States and Puerto Rico (Hispanic Association of Colleges and Universities, 2020). As such, HSIs comprise an important pathway to consider for the origin of Hispanic and Latino doctorate degree holders and faculty.

2.2 | MSIs and graduate education

Although MSIs comprise only a small fraction of the total number of bachelor's degree-granting institutions, they play a tremendous role in launching Black/African American and Hispanic/Latino students into scientific and engineering (S&E) disciplines. For example, HBCUs comprise less than 3% of postsecondary institutions in the United States, but in 2010, they granted 19% of S&E bachelor's degrees awarded to Black students (Gasman & Nguyen, 2014). Furthermore, when controlling for institutional information, such as standardized test scores, Carnegie classification, and faculty-to-student ratios, HBCUs produced twice as many future engineering doctorates than other institutions with similar characteristics (Sibulkin & Butler, 2011). There are limited options for students who want to earn an engineering PhD from an HBCU, as only 22% of HBCUs offer such degree programs (Palmer & Gasman, 2008). One study of Black students who earned both their BS and PhD from US institutions found that only 12% earned PhDs from HBCUs. In contrast, the majority of Black graduates (62%) earned both their BS and PhD from PWIs (Upton & Tanenbaum, 2014).

Similar to HBCUs, HSIs have also been shown to make outsized contributions in this area. For example, recognizing the different experiences of people from Hispanic/Latino countries, Solórzano investigated the baccalaureate origins of Chicano/a (Mexican-American) doctorates in science and engineering, finding that such individuals were more likely to earn their bachelor's degrees from HSIs, primarily those in the southwestern United States with teaching-focused missions (Solórzano, 1994). He also found that when controlling for institution size, future Chicano/a science and engineering doctorates disproportionately attended small private colleges—a type of institution typically overlooked in rankings. More recently, HSIs have had more growth in Latino/a undergraduate engineering graduates than non-HSIs: between 1994 and 2001, HSIs had a 36% increase, compared with 23% for non-HSIs (Camacho & Lord, 2011). HSIs also award a disproportionately higher percentage of undergraduate degrees to Latino students; 67% of Latino undergraduates attend an HSI, despite the fact that HSIs account for only 17% of all higher education institutions (Excelencia in Education, 2019). Additionally, one third of engineering BS degrees earned by Hispanic/Latino students were from HSIs, despite HSIs housing only 9% of all undergraduate engineering programs (Anderson et al., 2018).

2.3 | Institutional prestige

The *US News and World Report* (USNWR) rankings for undergraduate and graduate programs are one of the most influential measures of institutional prestige (Sweitzer & Volkwein, 2009). When an institution moves onto the front page (Top 25) of USNWR, they see substantial increases in admission indicators the following year (Bowman & Bastedo, 2009). Unfortunately, there are many ways in which this institutional ranking system is biased; merely being included in the published rankings has a significant impact on future peer assessment scores (Bastedo & Bowman, 2010). For example, the ranking criteria for undergraduate engineering institutions rely solely on surveying the opinions of deans and senior faculty at peer institutions, which makes the rankings highly subjective and open to personal bias. The ranking for graduate engineering programs at the subdiscipline level (e.g., mechanical engineering) is similarly based 40% on peer evaluations and corporate recruiter scores, but college-level graduate rankings for engineering are more well-defined and quantitatively measurable.

These factors bias rankings toward large institutions with more resources, which often works against HBCUs and HSIs. One-quarter of a college-level engineering program rank is based on its research expenditures: its total research expenditure (externally funded) and average research expenditures per faculty member. Another one-quarter of rank is based on faculty resources: the number of doctoral degrees awarded, ratio of MS and PhD students to tenure-track faculty, and percentage of faculty elected to the National Academy of Engineering. However, what is not as obvious is the self-fulfilling prophecy of ranked institutions receiving more money: one study found that USNWR exposure led to a 6.5% increase in state-funded expenditures per student (Jin & Whalley, 2007). Additionally, 10% of a graduate program's score is based on enrolled students' quantitative GRE score, which has been shown to be biased against women and underrepresented minorities (Bleske-Rechek & Browne, 2014).

Institutional prestige is important to consider in this conversation because it is a key factor in graduate admissions criteria. Undergraduate institutional prestige is one of the first considerations of committees when assessing applications (in addition to GRE/TOEFL scores and GPA, Posselt, 2014). However, the majority of Black science and engineering PhD graduates earned their bachelor's degrees from "less prestigious" institutions (i.e., HBCUs and those not in the highest research activity classification, Solórzano, 1995). In 2013, of the Top 50 institutions producing Black bachelor's degree holders who went on to earn their PhDs in science and engineering, 29 were PWIs and 21 were HBCUs (Toldson, 2018). According to the Hispanic Association for Colleges and Universities' (HACU) list of HSIs for 2018–2019 (Hispanic Association of Colleges and Universities, 2020), no HSI institutions are ranked within the Top 25 engineering program rankings, either at the undergraduate or graduate levels. Additionally, there are no HBCUs ranked within the Top 25 engineering program rankings at either level.

Institutional prestige also plays a tremendous role in the hiring process after PhD graduation. Not all PhD degrees are perceived as equal by faculty search committees, and candidates at highly ranked programs are largely hired from only a small pool of highly ranked institutions. In computer science, for example, roughly one-quarter of PhD-granting institutions produce approximately 80% of all tenure-track computer science faculty (Clauset et al., 2015). Further, in other fields it has been observed that the importance of institutional prestige does not apply equally to all candidates. In a study on hiring academic administrators, 80% of subjects evaluating a Latino candidate cited doctoral institution as very important, compared with only 55% of subjects evaluating a White man candidate (Haro, 1995). These differences in hiring practices are yet another contributor to the cumulative disadvantage faced by Black/African American and Hispanic/Latino scholars. Students' undergraduate institution of attendance may influence their recruitment to top-faculty-producing graduate programs, which may translate to a reduced likelihood of an individual having an opportunity to become a tenure-track faculty member.

In our study, we quantify the extent to which institutional ranking and type remain consistent from an individual's bachelor's to master's and PhD programs and from PhD programs to tenure-track faculty positions for Black/African American and Hispanic/Latino engineers and computer scientists. Individuals moving through these pathways are subject to spheres of influence much greater than themselves. To understand this, we must consider a framework that can describe such impacts.

2.4 | Conceptual framework

We utilize Bronfenbrenner's (1979) ecological framework as a conceptual framework for logically organizing our analyses. Generally, an ecological framework is used to place focus on the role of the environment in individuals' learning and transition processes. Bronfenbrenner centers an individual and their decision-making within multiple, interrelated, contextual spheres of influence. Ecological transitions, or changes in roles or settings throughout life, are at the heart of this approach. Transitions, such as selecting and entering graduate school or a career after graduate school, are of crucial developmental importance because they require a change in one's role, which usually results in behavioral adaptations. This framework considers both individual settings and relationships with different levels of external settings regardless of whether an individual is a direct actor in the system. Namely, four levels of systems undergird the ecological framework: (1) microsystems (settings and relationships experienced directly by the individual, e.g., families, academic programs, research groups, and peer groups), (2) mesosystems (interactions between various settings in which the individual is an active participant, e.g., research group–academic program interactions), (3) exosystems (settings in which the individual does not actively participate, yet is influenced by nonetheless, e.g., industry partners for university research), and (4) macrosystem (cultures) (Bronfenbrenner, 1979).

Graduate students rely on strategic perspectives or take strategic and purposeful actions at the individual level to achieve goals that are important to them (Borrego et al., 2021; Boud & Lee, 2005; O'Meara et al., 2014). Simultaneously, however, graduate students are embedded within overlapping networks and social contexts that influence their learning and decision-making (Baker & Lattuca, 2010), such as interpreting messages about job markets and desirable career paths. Engineering graduate students' past teaching and personal experiences influence their perceptions of competence and autonomy as well as how they think about their futures (Kajfez & Matusovich, 2017; Tsugawa-Nieves et al., 2017). Thus, ecological frameworks have been useful for examining phenomena in graduate education. For example, research on graduate students has highlighted the importance of both personal and situational factors—both of which are emphasized in the ecological approach—on graduate students' career decisions (Haley et al., 2014). Lau and Ng (2014) applied Bronfenbrenner's ecological framework to conceptualize and evaluate the educational environments of counselor graduate trainee programs, examining micro- through macrosystem effects. Similarly, this ecological framework has been applied to explain the role that doctoral supervisors (part of a student's microsystem) play in helping advisees' transition between different educational systems, national contexts, and modes of thinking within graduate school (Elliot & Kobayashi, 2019).

Most of the work around support of traditionally marginalized students in engineering has focused on undergraduate mentorship (Bowen et al., 2021; Mondisa, 2020; Mondisa & Adams, 2022; Washington & Mondisa, 2021), undergraduate identity and competency development (McCall et al., 2021; Polmear et al., 2021), or faculty support (Diggs & Mondisa, 2022; Jackson et al., 2020). Some work has been conducted in the space of graduate education. Research has focused on the relationships and support systems of minoritized graduate students, such as how the academic and social interactions (e.g., exposure to industry settings or having academic mentors) of URM graduate students can positively shape their career goals (Amelink & Artiles, 2021). Similarly, early doctoral interventions such as cohort-based support institutes (Artiles et al., 2021), transparent conversations on the process of advisor–advisee matching in academic departments (Artiles & Matusovich, 2022), and an understanding of hidden curricula (Gelles et al., 2019) have proven to be promising for helping traditionally marginalized doctoral students find success in their programs. Similarly, the ways a graduate student's identity is developed and supported has a direct impact on their perceived career prospects (Gelles & Villanueva, 2020; Villanueva et al., 2018, 2019), and White students report higher levels of engineering identity than their peers who are students of color (Bahnson et al., 2021). In terms of support after graduation, research has demonstrated that postdoctoral training can provide a good pathway into engineering careers in academia (Main et al., 2021a) and that access to professional development opportunities can enhance women's pathways to leadership roles both in industry and academia (Main et al., 2021b; Wang & Main, 2021). While these studies increase our understanding of the dynamics students must navigate, they focus largely on issues that exist at the microsystem level. We complement this existing research by providing a bigger picture at a systemic level—using Bronfenbrenner's conceptualization, our analysis considers the exosystem layer (i.e., the higher education institutional context).

Scholars have explicitly called for more research from the ecological perspective. As Flynn et al.'s (2011) review of research on graduate students of color noted, most studies focus on individual or microsystems, as opposed to broader environmental influences. Similarly, Gibbs et al.'s (2014) study of career interest patterns by gender and race/ethnicity for biomedical science PhD students argued that ecological frameworks are crucial for workforce development and broadening participation efforts. Such frameworks not only allow for individual variation but also emphasize the important influence of multiple agents in career decisions and transitions that may be overlooked by the more individual-focused frameworks typically used in graduate education research. In the current study, we consider the exosystem in terms of the institutions from which students earn their degrees and the macrosystem of the cultures, norms, and practices across academic institutions. Groupings of institutions (e.g., by ranking and status as an MSI or non-US institution) can offer insights regarding the nature of students' educational experiences and ability to transition between different institutional groupings over time.

We couple this ecological perspective with an organizational perspective known as the "Matthew effect." Merton (1968) used this Biblical reference to describe the concept of cumulative advantage, the notion that the rich get richer while the poor get poorer. In a scientific career at the individual level, he points out, the earlier an individual has opportunities and resources, the more the individual's career will continue to benefit later on. Attending a prestigious institution is the earliest and easiest way a young scientist can begin to accumulate advantage.

3 | METHODS

3.1 | Positionality

As researchers in this field, we are interested in understanding not only the pathways that Black/African American and Hispanic/Latino PhD graduates take to obtain PhDs and tenure-track faculty positions, but also how institutional practices expand or limit these pathways. Given that many studies of this scale focus on majority students or include a combined Black/African American and Hispanic/Latino group compared with the majority, we intentionally choose to disaggregate and focus only on these two groups.

Our author team includes one multiracial woman, one Black woman, one Black man, one Latino man, two White women, and two White men. We are at varied career stages, including postdocs, a graduate student, and tenure-track faculty members. One author was employed by an HBCU while working on this study, but the rest of us have limited experience with MSIs. One of the authors previously managed a professional development program at a PWI to encourage engineering PhD students and graduates from underrepresented groups to pursue careers in academia. The five faculty members have served on graduate admissions committees, faculty hiring committees, and as program directors. One faculty member was previously an associate dean in a graduate school. Another faculty member was previously an assistant dean for teaching and learning at a technical university, and his tenure focused on implementation of inclusive pedagogical practices in six engineering programs.

We have educational and employment histories at highly ranked institutions and acknowledge that we have personally benefitted from the privilege of the perceptions that go along with those histories. We also work at institutions that place great importance on the ranking systems discussed and critiqued in this paper. As such, we take some risk in criticizing such a well-established and widely regarded ranking system. Nevertheless, we firmly believe it is dangerous to use rankings in the way they commonly are used, which is to reinforce an inequitable system. We highlight these issues so that people will recognize the problem and bring about change.

3.2 | Data sources

This quantitative study utilized two data sources. The Survey of Earned Doctorates (SED) is an annual census of all graduating doctorate recipients earning a research doctorate in the United States. The SED is sponsored by the NCSES within NSF as well as the National Institutes of Health (NIH), Department of Education, and National Endowment for the Humanities. The SED is considered to be census data (the 2019 survey had a population size of 55,703 and response rate of 92%) and is used to understand national-level trends in doctoral education by collecting information about doctorate earners' educational history, demographic data, and postgraduation plans (NSF, 2021). In terms of data available in the SED, our paper focuses primarily on graduates' bachelor's, master's, and doctoral institutions. We used the HSI designation from the HACU 2018–19 list (Hispanic Association of Colleges and Universities, 2020), and we collected college-level engineering program ranking data from the 2021 *US News and World Report* (USNWR, 2020). We used the Integrated Postsecondary Education Data System (IPEDS) to assign institution names to their corresponding institution codes to assist in our interpretation of the results. We provide more details about the SED variables used and the data collected in the Sample and Institution Variable sections.

The Survey of Doctorate Recipients (SDR), which is also sponsored by NCSES and NIH, is administered every 2 years (NCSES, 2021a, 2021b). Survey respondents include prior recipients of a research-based doctorate degree in science, engineering, or health at an institution in the United States. Similar to the SED, the SDR is a national, multi-institutional data set. Unlike the SED, the SDR contains a sample of respondents, rather than a census of the entire population. For example, although 85,739 respondents filled out the SDR in 2017, those respondents spanned cohorts that graduated between 1964 and 2016. The SDR is distributed to individuals who previously responded to the SED, which allows SED and SDR responses to be linked using participant IDs. Questions in the SDR broadly focus on respondents' current and past employment, work-related experiences, educational experiences, and demographics. For the purpose of our analysis, we focused on respondents' position and institution in the section on current employment. We provide greater detail on specific items used during analysis in the Sample and Institution Variables sections.

3.3 | Sample

All respondents in this paper's sample identified as Black/African American and/or Hispanic/Latino and earned a doctorate in engineering or computer science between 2000 and 2015 (note: the sample was extracted from the larger SED and SDR populations as previously described; our team followed secure data access protocols as established by NCSES and the data stewards at the National Opinion Research Center at the University of Chicago to protect individual survey respondents). We chose to include computer science doctorates in the analysis for two reasons: (1) computer science is included within engineering schools at many institutions, and (2) similar patterns of racial/ethnic composition exist in computer science as in engineering. We scoped our sample to PhDs earned within the calendar years of 2000–2015 to understand recent trends in completion of doctorate degrees. This date range also allowed us to track resulting career pathways following degree completion. Respondents were intentionally included regardless of citizenship status so we could provide a comprehensive overview of all Black/African American and Hispanic/Latino pathways and remain inclusive of non-US students, who comprise a substantial proportion of engineering and computer science graduate students in the United States.

Race/ethnicity categorization followed the same procedure for RQ 1 and RQ 2. Respondents were classified as Black/African American based on their responses to the SED question "What is your racial background?" Respondents could mark multiple responses. We categorized respondents as Black/African American if they selected "Black or African American," including respondents who also selected other racial backgrounds. Respondents were categorized as Hispanic/Latino if they selected any of the options to the question "Are you Hispanic or Latino?" ("Yes, Mexican or Chicano"; "Yes, Puerto Rican"; "Yes, Cuban"; "Yes, other or unspecified Hispanic or Latino"; "Yes, Hispanic, but origin unknown"). We recognize that there can be different experiences for people within this group, but disaggregating data to this level would have resulted in substantial limitations in analysis of pathways data and omissions of subgroups to protect confidentiality of respondents. Additionally, by including multiracial respondents for both Black/African American and Hispanic/Latino groups, there was some overlap in the subpopulations for respondents identifying as both Black/African American and Hispanic/Latino. These decisions were in effort to be comprehensive in our understanding of Black/African American and Hispanic/Latino pathways to doctorate completion and tenure-track roles in engineering and computer science. More work remains to take advantage of more nuanced race/ethnicity data from large-scale survey data like SED and SDR without sacrificing the anonymity of respondents.

Some respondents were multiracial, that is, both Black/African American and Hispanic/Latino, and therefore counted twice in our analysis. For the SED BS-to-PhD pathways, 348 respondents identified as both Black/African American and Hispanic/Latino, accounting for 9% of all Black/African American respondents in our analysis. For the SDR tenure-track analysis, nine respondents identify as both Black/African American and Hispanic/Latino. Due to small numbers in the pathway, we dropped one of the multiracial respondents from the visualization of results for Black TT pathways. There are eight multiracial respondents in Figure 3 and nine multiracial respondents in Figure 4.

For RQ 2, we examined Black/African American and Hispanic/Latino respondents who held tenure-track faculty roles using data from both the SED and SDR, linking respondents using participant IDs. The linked SED–SDR data used in the tenure-track analysis is a subset of the SED data sets for the PhD pathways analysis. The SED–SDR sample of tenure-track faculty (hereafter called the "tenure-track faculty sample") includes respondents who identified as Black/African American and/or Hispanic/Latino, earned a doctorate in engineering or computer science between 2000 and

2015, and held tenure-track employment in 2017 as indicated in the 2017 SDR (the most recent SDR survey data available to our research team). We decided to use one timepoint of the SDR to understand employment outcomes, rather than tracking respondents through multiple waves of the SDR. Consistent with our ecological framework, this approach allowed us to focus on a broad overview of the state of tenure-track employment instead of a longitudinal analysis of individual respondents' trajectories. This method resulted in a linked tenure-track faculty sample containing respondents in tenure-track roles who were early to mid-career, specifically who earned their doctorate degree 2–17 years prior. We removed respondents in the SED sample who had not responded to the SDR in 2017. Then, we filtered those respondents using the variables TENSTA and FACRANK (described in Table 2) to include only respondents who had already earned tenure or were on the tenure track in assistant professor, associate professor, or professor positions at an educational institution. Respondents in nontenured academic roles or who indicated they were in tenured/tenure-track administrative positions were excluded from analyses to focus the findings on respondents who were serving in tenure-track faculty roles within the time frame of our study. While such individuals are important to the overall landscape, given the variation in roles, we chose to focus the current analysis on tenure-track and tenured faculty.

3.4 | Institutional variables

Our analysis centers primarily on understanding institutional pathways and institutional characteristics for Black/African American and Hispanic/Latino respondents, through the doctorate and into tenure-track faculty positions. The institutional variable names, sources, and descriptions for our two research questions are given in Tables 1 and 2.

TABLE 1 Institutional variable names, sources, and descriptions for RQ 1

Variable name	Data source	Description/notes
SED	National Science Foundation	Survey of Earned Doctorates
SDR	National Science Foundation	Survey of Doctorate Recipients
BAINST	SED	Respondent's bachelor's institution
MAINST	SED	Respondent's master's institution
PHDINST	SED	Respondent's PhD institution
BAHBCU	SED	Yes/No if respondent's bachelor's institution was an HBCU
MAHBCU	SED	Yes/No if respondent's master's institution was an HBCU
PHDHBCU	SED	Yes/No if respondent's PhD institution was an HBCU
BS NonUS MA NonUS	SED	Respondents who earned their bachelor's or master's degrees at a non-US institution
BAHSI	SED, HACU	Yes/No if respondent's bachelor's institution was an HSI
MAHSI	SED, HACU	Yes/No if respondent's master's institution was an HSI
PHDHSI	SED, HACU	Yes/No if respondent's PhD institution was an HSI
Top 10 BS	SED, 2021 USNWR	College-level engineering program rankings for US undergraduate engineering schools offering a doctorate. Ten institutions were included in this category.
Top 11–25 BS	SED, 2021 USNWR	Since five institutions tied for the ranking of 22nd, we included all institutions in the category of Top 11–25, for a total of 17 institutions
Not Top 25 BS	SED, 2021 USNWR	All other BS institutions not included in Top 10 BS and Top 11–15 BS
Top 10 MS Top 10 PhD	SED, 2021 USNWR	Master's and PhD US institution rankings according to USNWR graduate engineering programs. Due to a three-way tie for 10th place, 12 institutions are included in the Top 10.
Top 11–25 MS Top 11–25 PhD	SED, 2021 USNWR	Due to a three-way tie for 24th place and a three-way tie for 10th, 14 institutions were included in these categories.
Not Top 25 MS Not Top 25 PhD	SED, 2021 USNWR	All other master's and PhD institutions not included in Top 10 MS/PhD and Top 11–25 MS/PhD

TABLE 2 Institutional variable names, sources, and descriptions for RQ 2

Variable name	Data source	Description/notes
Top 25 PhD	SED, 2021 USNWR	Same notes as above; 26 institutions are included in this category (Top 10 PhD and Top 11–25 PhD combined)
Not Top 25 PhD	SED, 2021 USNWR	Same notes as above; in addition, all HBCUs and HSIs are included in this category due to small sample sizes in the data set
INSTCOD	SDR, IPEDS	Respondents' tenured/tenure-track institution
TENSTA	SDR	Tenure status (i.e., tenure track, tenured, not on tenure track)
FACRANK	SDR	Faculty rank (e.g., assistant professor, associate professor, lecturer, etc.)
HBCU TT	SDR, SED	HBCUs where respondents hold tenured/tenure-track positions
HSI TT	SDR, HACU 2018–19	HSIs where respondents hold tenured/tenure-track positions
Top 25 TT	SDR, 2021 USNWR	US institution rankings according to USNWR graduate engineering programs, for respondents' tenured/tenure-track institution (26 institutions included in this category)
Not Top 25 TT	SDR, 2021 USNWR	US institution rankings according to USNWR graduate engineering programs, for respondents' tenured/tenure-track institution
Non-US TT	SDR	Institutions outside the United States where respondents hold tenured/tenure-track positions

As previously noted, at the time of this analysis, no HBCUs or HSIs were listed on the 2021 US News & World Report's undergraduate and graduate college-level Top 25 engineering program rankings.

3.5 | Data analysis

Our primary motivation for this study was to understand the institutional pathways for Black/African American and Hispanic/Latino engineering and computer science PhD earners, as well as the pathways for those PhD earners who continued on to tenure-track faculty positions. As such, our analysis involved generating and analyzing how many Black/African American and Hispanic/Latino participants moved between institution types, analyzing two pathways: (1) to a PhD and (2) from a PhD to tenure-track faculty position. We calculated percentages for the movements between institution types at each point in the degree pathway (i.e., BS to MS institutions, MS to PhD institutions, and PhD to tenure-track institutions) and generated diagrams to visualize the pathways of respondents. Institutional variables (i.e., ranking and MSI status) allowed us to make inferences about the exosystem and macrosystem surrounding students' educational paths following the conceptual underpinnings of Bronfenbrenner's ecological framework. For example, we counted the number of PhD earners who attended an HBCU for their BS and transitioned to a Top 25 institution for their MS and separately counted those who attended an HBCU for both their BS and MS degrees. For the PhD pathways analysis, there were 30 potential BS to MS pathways and 24 potential MS to PhD pathways. For the tenure-track pathway analysis, there were eight potential pathways from a PhD to TT faculty position. In accordance with our data licensing agreement, any pathways where $n < 5$ were removed to protect anonymity of respondents. For RQ 1 analysis, a total of nine respondents were removed, and for RQ 2 analysis, five respondents were removed—these pathways do not appear in the diagrams.

Sankey diagrams (visual representation of pathways between timepoints) can display pathways from one point to another, with the pathway width corresponding to the proportion of that pathway. Although Sankey diagrams have historically been used to display energy balances (Alexander et al., 2019), their use in education research, and engineering education research specifically, has increased in recent years. Prior studies have used Sankey diagrams to display engineering career pathways (Rohde et al., 2020) and enrollment trends in engineering (Orr et al., 2014). There is great value in such descriptive and visual quantitative analyses, particularly in understanding the function and role of higher education systems (Loeb et al., 2017). Our Sankey diagrams should be read from left to right, with the RQ 1 Sankey diagrams showing pathways from BS to MS to PhD institutions and the RQ 2 Sankey diagrams showing pathways from PhD to tenure-track faculty institutions.

3.6 | Limitations

An important caveat in interpreting results is that the respondents to these surveys comprise only individuals who completed their doctorate. Graduate students do not persist in their programs for a variety of reasons (Berdanier et al., 2020), and prior work has shown how unsupportive educational environments create unique challenges and barriers for racially minoritized students within engineering (Burt et al., 2018; Figueroa & Hurtado, 2013; McGee et al., 2019). Based on the available data set, our analyses are not able to capture that broader phenomenon. We are unaware of a national-scale data set that would enable such analysis of graduate student attrition but recommend that individual institutions pay close attention to their own graduate student retention data, disaggregated by students' race/ethnicity. Moreover, for analyses that display pathways to faculty positions, the SDR followed a sampling approach as opposed to a whole population approach like the Survey of Earned Doctorates—it provides insights on patterns but should not be interpreted as representing the pathways of all doctorate earners.

Our data licensing agreement limits the reporting of small numbers ($n < 5$) to ensure individual respondents cannot be identified, which means some populations cannot be reported, and some strands had to be removed from the Sankey diagrams. We originally intended to include respondents identifying as American Indian/Alaskan Native and Hawaiian/Pacific Islander in our analysis. However, the numbers were nonreportable for the RQ 2 analysis because of our data licensing agreement. We also intended to analyze the role of Tribal Colleges in the pathways; however, the role of these institutions is limited for non-American Indian/Alaskan Native populations, and many institutions with this classification are 2-year institutions outside of the scope of the study. We also recognize the limitations of racial/ethnic identification through survey instruments, as we previously acknowledged. The institutional rankings and HSI status lists change slightly every year. Although we did our best to use the most recent data available to us, our data are limited in that they reflect only a snapshot in time for institutions' statuses for these variables. We acknowledge that in the time it has taken to complete and publish this analysis, multiple Top 25 institutions have been designated as HSIs, including one of the authors' institutions.

For RQ 1, there were many respondents who did not complete a master's degree. Earning a master's degree en route to a doctorate can be field- or institution-dependent, so we do not consider this phenomenon as a major finding. Results should be interpreted with that context in mind. For RQ 2, respondents who attended an MSI (either HSI or HBCU) for their PhD and currently hold tenure-track faculty roles are not presented in this paper in their own MSI category because our data licensing agreement prohibits the publication of counts data less than five. Instead, these individuals are included in the "Not Top 25" category. Additionally, because of the limited sample size, we also combined the Top 10 and Top 11–25 categories into one category ("Top 25") for RQ 2. Finally, the Sankey diagrams highlight and succinctly display how individuals move within educational systems, but we cannot interpret why students make certain decisions from our analysis or determine the direct causation of pathways (e.g., systemic inequalities, individual agency and choice, etc.). This systems-level analysis is an important step for gaining a cohesive understanding of movement and pathways throughout educational systems for Black/African American and Hispanic/Latino doctorate earners in engineering and computer science.

Many tenure-track faculty do not transition directly from their PhD to a faculty position. Working as a postdoctoral researcher first is becoming increasingly common, and engineering PhD earners who completed a postdoc are more likely to obtain a tenure-track faculty position than those who did not complete a postdoc (Main et al., 2021a). Only one third of postdocs in the physical sciences and engineering transition from a postdoc to a tenure-track position within 5–6 years of completing their PhD (Denton et al., 2022). In this paper, we do not examine the role of postdoc positions (duration or prestige of postdoc institution) and how they might influence institutional mobility.

4 | RESULTS

4.1 | Pathways to engineering and computer science PhDs for Black/African American students

We visualized the BS–MS–PhD pathways for 3953 Black/African American engineering and computer science PhD earners from 2000 to 2015 using the Sankey diagram shown in Figure 1. The key findings from this data analysis are as follows: (1) there is a relative lack of mobility between institution categories; (2) a large percentage earned their MS and/or PhD at a Not Top 25 institution (MS: 49%, $n = 1953$; PhD: 62%, $n = 2453$); and (3) a large percentage (31%, $n = 1218$) of Black/African American doctorate earners earned their BS at a non-US institution. Additionally, although

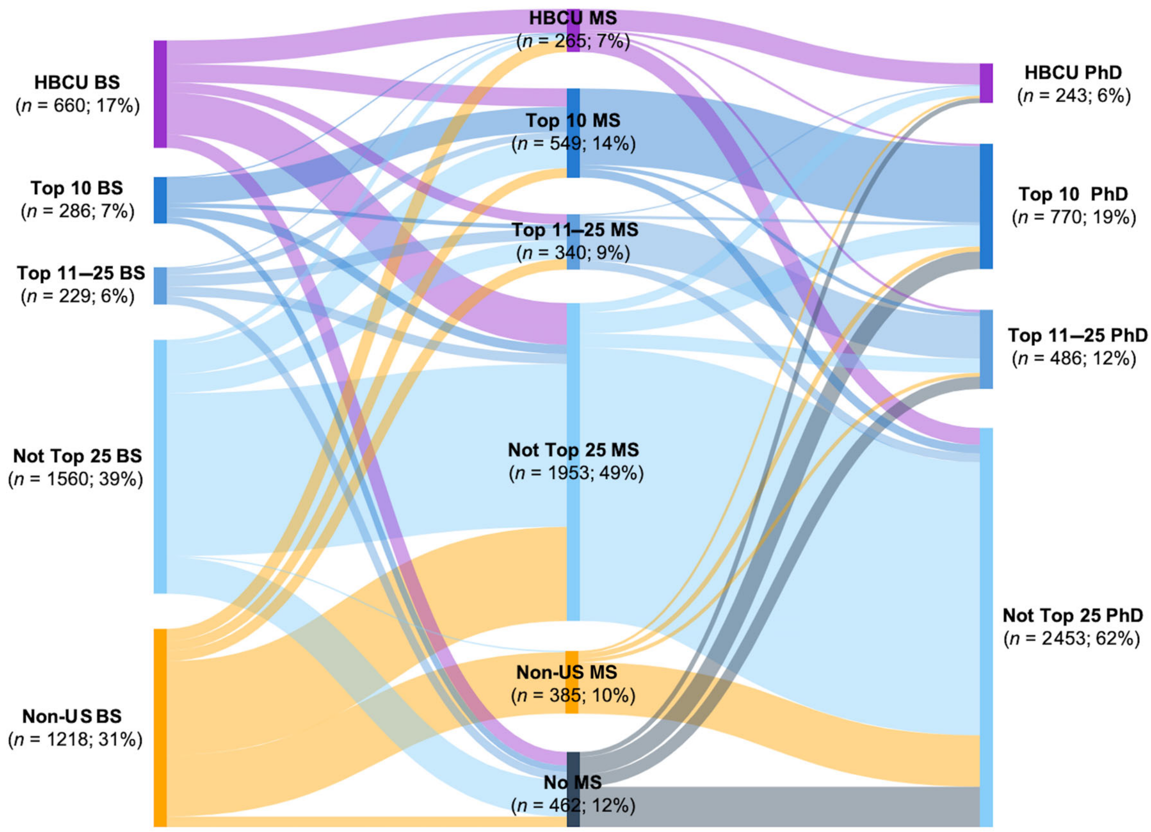

FIGURE 1 Sankey diagram of BS–MS–PhD pathways for Black/African American SED respondents (2000–2015)

many respondents (17%) earned their BS at an HBCU, smaller percentages earned their MS (7%) or PhD (6%) at an HBCU (note: the majority of HBCUs offer only BS degrees).

Mobility between institution categories was limited, particularly from MS to PhD. Respondents who attended an HBCU for their MS were the most mobile between institution categories for their PhD, with only 50% ($n = 130$) continuing their PhD at an HBCU. Of those 130 respondents, 92% ($n = 120$) completed their MS and PhD at the same institution. Among the remaining respondents who transitioned from an HBCU for their MS to a non-HBCU for their PhD, 40% ($n = 104$) moved to a Not Top 25 institution, with fewer transitioning to a Top 10 (5%, $n = 12$) or Top 11–25 (5%, $n = 16$) institution. Mobility for Black/African American respondents was most limited for those who completed their MS at Not Top 25 institution. A large majority (86%, $n = 1678$) of those respondents continued their PhD at a Not Top 25 institution, 61% ($n = 1017$) of which did so at the same institution. Far fewer respondents moved to a Top 10 (7%, $n = 129$) or Top 11–25 (4%, $n = 87$) institution, and 3% ($n = 59$) transitioned to an HBCU for their PhD. Black/African American respondents who completed their MS at a Top 10 institution largely completed their PhD at a Top 10 institution (86%, $n = 469$), the vast majority (93%, $n = 438$) doing so at the same institution. The remaining respondents transitioned to Top 11–25 (5%, $n = 25$) or Not Top 25 (10%, $n = 53$) institutions for their PhD. Finally, 76% ($n = 259$) of Black/African American respondents who completed their MS at a Top 11–25 institution completed a PhD in the same institutional category, 97% ($n = 250$) of which stayed at the same institution. Of the remaining respondents who transitioned across institutional categories, 5% ($n = 18$) moved to a Top 10 institution, 16% ($n = 54$) to a Not Top 25 institution, and 3% ($n = 9$) to an HBCU to complete their PhD.

Given the large percentages of students completing their MS and PhD in the same institutional category, understanding movement between institutions on the pathway to a doctorate should focus on movement from students' BS institutions, where we observed more movement. For example, MS earners at Top 10 institutions moved from a variety of BS institution categories: 33% moved from Not Top 25 BS institutions ($n = 181$), 28% from Top 10 ($n = 156$), 20% from HBCUs ($n = 112$), 11% from non-US ($n = 60$), and 7% from Top 11–25 ($n = 40$). Other types of MS institutions had similar distributions. The widest paths stayed fairly consistent from BS to MS for Top 10 and Not Top 25 institutions (i.e., once in a Top 10/Not Top 25 institution for a BS, the largest percentage of students remained in a Top 10/Not Top 25 institution for the MS). Although we observed some movement between categories of institutions from the BS to MS,

Figure 1 shows limited mobility between MS and PhD institution types. Thus, we find that students and graduate programs should not consider an MS as a "stepping stone" to a PhD institution in a different category.

We also observe a prevalence of Not Top 25 institutions across the pathways diagram for Black/African American engineering and computer science PhDs. Not Top 25 institutions account for the most degrees at all three education levels: 40% ($n = 1560$) of BS degrees, 49% ($n = 1953$) of MS degrees, and 62% ($n = 2453$) of PhDs. Finally, a substantial number of doctorate earners earned their BS at a non-US institution. Of all Black/African American engineering and computer science degree earners in the United States between 2000 and 2015, 31% ($n = 1218$) earned their BS from a non-US institution. From this group, the majority completed their MS at a Not Top 25 institution (48%, $n = 578$) or at a non-US institution (31%, $n = 377$), with far fewer attending an HBCU (6%, $n = 74$), Top 10 (5%, $n = 60$), or Top 11–25 (5%, $n = 64$) institution for their MS. Most of the students who completed their MS at a non-US institution completed a PhD at a Not Top 25 institution (82%, $n = 316$), with smaller percentages transitioning to an HBCU (4%, $n = 15$), Top 10 (8%, $n = 31$), or Top 25 (6%, $n = 23$) institution to complete their PhD.

4.2 | Pathways to engineering and computer science PhDs for Hispanic/Latino students

We conducted similar analyses for Hispanic/Latino engineering and computer science PhD earners from 2000 to 2015 ($n = 5729$), as provided in Figure 2. Two main takeaways are (1) there is a relative lack of mobility between institution categories, and (2) a large percentage (55%) of PhD earners obtained their BS from a non-US institution. Additionally, similar proportions of respondents earned their BS (16%), MS (14%), and PhD (17%) at an HSI. In contrast to Black/African American PhD earners, Hispanic/Latino PhD earners did not generally graduate from Not Top 25 institutions: only 17% ($n = 986$) of BS degrees, 32% ($n = 1839$) of MS degrees, and 46% of PhD degrees were earned at Not Top 25 institutions.

Mobility between institution categories was also limited for Hispanic/Latino PhD respondents from MS to PhD. Respondents who attended an HSI for their MS were the most mobile between institution categories for their PhD,

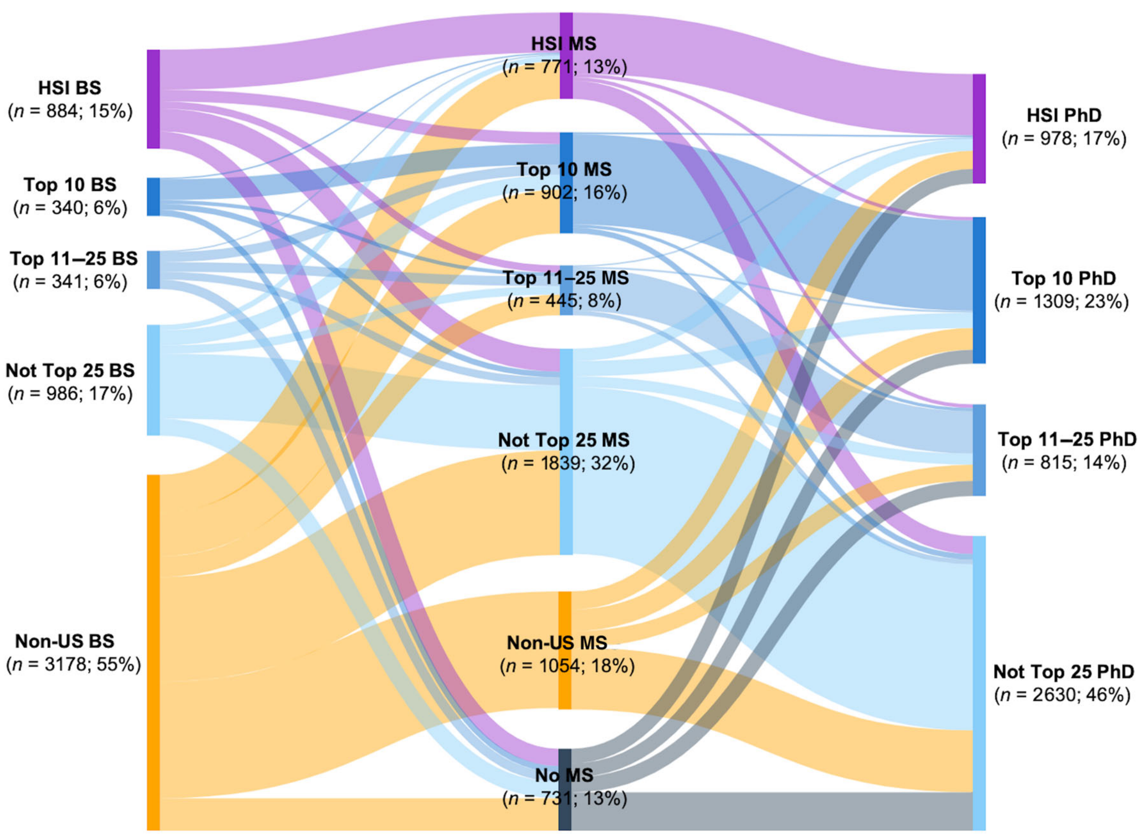

FIGURE 2 Sankey diagram of BS–MS–PhD pathways for Hispanic/Latino SED respondents (2000–2015)

FIGURE 3 Sankey diagram of PhD-to tenure-track positions (TT) pathways for Black/African American SED + SDR respondents

FIGURE 4 Sankey diagram of PhD-to-tenure-track positions (TT) pathways for Hispanic/Latino SED + SDR respondents

with 71% ($n = 547$) continuing the PhD at an HSI. Of those 547 respondents, 88% ($n = 482$) completed their MS and PhD at the same institution. Among the remaining respondents who transitioned from an HSI for their MS to another institutional category for their PhD, 21% ($n = 160$) moved to a Not Top 25 institution, with comparably fewer transitioning to a Top 10 (4%, $n = 31$) or Top 11–25 (4%, $n = 33$) institution. For Hispanic/Latino respondents who completed their MS at a Not Top 25 institution, a large majority (81%, $n = 1484$) of those respondents continued their PhD at a Not Top 25 institution, 75% ($n = 1113$) of which did so at the same institution. Far fewer respondents moved to a Top 10 (7%, $n = 137$) or Top 11–25 (5%, $n = 98$) institution, and 6% ($n = 110$) transitioned to an HSI for their PhD. The vast majority of Hispanic/Latino respondents who completed their MS at a Top 10 institution completed their PhD at a Top 10 institution (89%, $n = 806$), 94% ($n = 438$) of which did so at the same institution. The remaining respondents transitioned to a Top 11–25 institution (3%, $n = 29$), Not Top 25 institution (6%, $n = 50$), or an HSI (2%, $n = 17$) for their PhD. Finally, 84% ($n = 375$) of Hispanic/Latino respondents who completed their MS at a Top 11–25 institution completed a PhD in the same institutional category, 98% ($n = 366$) of which stayed at the same institution. Of the

TABLE 3 Percentages of PhDs earned at different categories of ranked institutions

	This study: Black/African American PhDs	This study: Hispanic/Latino PhDs	All 2019 PhD earners[a]
Top 10	19%	23%	21%
Top 11–25	12%	14%	21%
Not Top 25	69%	63%	58%

[a]These percentages were calculated by cross-referencing the numbers of PhD earners (Roy, 2019) with the Top 25 institutions from the USNWR rankings list. Numbers were not available for Duke University (tie-#20), University of Pennsylvania (tie-#20), and Harvard University (tie-#25).

remaining respondents who transitioned across institutional categories, 4% ($n = 17$) moved to a Top 10 institution, 9% ($n = 41$) to a Not Top 25 institution, and 3% ($n = 12$) to an HSI to complete their PhD.

Movement between institution categories occurred more frequently when students transitioned from a BS to MS. For example, Top 10 MS earners moved from a variety of institutional categories: 43% from non-US BS institutions ($n = 391$), 21% from Top 10 institutions ($n = 185$), 15% from Not Top 25 institutions ($n = 133$), 12% from HSIs ($n = 104$), and 10% from Top 11–25 institutions ($n = 49$). Other categories of MS institutions had similar movements of incoming students. Again, we observed more limited mobility between MS and PhD institution types, as displayed by the thin strands in Figure 2.

Over half of Hispanic/Latino engineering and computer science PhD earners (55%, $n = 3178$) obtained their BS degree from a non-US institution. These respondents earned their MS degrees from mostly non-US institutions (33%, $n = 1014$) and Not Top 25 institutions (29%, $n = 934$), with smaller percentages earning their MS at Top 10 institutions (12%, $n = 391$), HSIs (11%, $n = 338$), Top 11–25 institutions (6%, $n = 185$), or not earning an MS at all (9%, $n = 289$). Of the non-US MS earners, the majority (52%, $n = 553$) earned their PhDs at Not Top 25 institutions. Nineteen percent ($n = 194$) earned PhDs at Top 10 institutions, 15% ($n = 162$) at HSIs, and 14% ($n = 145$) at Not Top 25 institutions.

Additionally, we examined distributions of PhD earners across the institutional categories to provide context for our focal subpopulations, as provided in Table 3. The percentage of PhDs earned by Black/African American and Hispanic/Latino engineers from the Top 10 institutions is similar to the percentage of degrees earned by all graduates from those institutions in 2019 (Roy, 2019). However, we notice large discrepancies in the percentages of PhDs earned from institutions in the Top 11–25, with significantly lower percentages of Black/African American and Hispanic/Latino students earning their PhDs from these institutions compared with all PhD earners.

4.3 | Pathways to tenure-track faculty roles for Black/African American doctorates

We visualized the pathways to a tenure-track position for Black/African American engineering and computer science PhD earners using the Sankey diagram in Figure 3. In the sample, 68% ($n = 71$) completed their PhD at Not Top 25 institutions and 32% ($n = 33$) completed their PhD at Top 25 institutions. Most respondents held tenure-track positions at Not Top 25 institutions (68%, $n = 71$), followed by HBCUs (18%, $n = 19$), Top 25 institutions (8%, $n = 8$), and non-US institutions (6%, $n = 6$). Of the respondents who earned doctorates from Top 25 institutions, 61% ($n = 20$) held tenure-track roles at Not Top 25 institutions, 24% ($n = 8$) at Top 25 institutions, and 15% ($n = 5$) at HBCUs. For respondents who earned doctorates from Not Top 25 institutions, 72% ($n = 51$) held tenure-track roles at Not Top 25 institutions, 20% ($n = 14$) at HBCUs, and 9% ($n = 6$) at non-US institutions. PhD institution category related to the frequency of tenure-track employment within a similar institution category, with limited (i.e., non-reportable) movement from a Not Top 25 PhD to Top 25 tenure-track position among this sample. Respondents in tenure-track roles at HBCUs had earned their PhDs at Not Top 25 (74%, $n = 14$) and Top 25 (26%, $n = 5$) institutions. Respondents in tenure-track roles at Not Top 25 institutions similarly earned their PhDs at Not Top 25 (72%, $n = 51$) and Top 25 (28%, $n = 20$) institutions.

4.4 | Pathways to tenure-track faculty roles for Hispanic/Latino doctorates

We visualized the pathways to a tenure-track position for Hispanic/Latino engineering and computer science PhD earners using the Sankey diagram in Figure 4. In the sample, 72% ($n = 152$) completed their PhD at Not Top

25 institutions, and 28% ($n = 59$) completed their PhD at Top 25 institutions. Most respondents in the sample held tenure-track positions at Not Top 25 institutions (40%, $n = 85$) or non-US institutions (36%, $n = 75$), followed by HSIs (21%, $n = 45$) and Top 25 institutions (3%, $n = 6$). Of those who earned their PhD from a Top 25 institution, 41% ($n = 24$) held tenure-track positions at Not Top 25 institutions, 32% ($n = 19$) at non-US institutions, 17% ($n = 10$) at HSIs, and 10% ($n = 6$) at Top 25 institutions. Of those who earned their PhD from a Not Top 25 institution, 40% ($n = 61$) held tenure-track positions at Not Top 25 institutions, 27% ($n = 56$) at non-US institutions, and 23% ($n = 35$) at HSIs. PhD institution ranking influenced the frequency of tenure-track employment at a similarly ranked institution, with limited (i.e., nonreportable) movement from Not Top 25 PhD to Top 25 tenure-track position. Respondents in tenure-track positions at HSIs, non-US institutions, and Not Top 25 institutions had received a mixture of Top 25 and Not Top 25 doctorates. Respondents in tenure-track positions at Not Top 25 institutions had the highest proportion of Top 25 doctorates (28%, $n = 24$), followed by non-US institutions (25%, $n = 19$) and HSIs (22%, $n = 10$).

5 | DISCUSSION

By taking an ecological perspective in grounding this study (Bronfenbrenner, 1979), we consider how larger structural systems may relate to the potential decisions and opportunities afforded to an individual. Our work follows calls from scholars such as Flynn et al. (2011) to take a broader ecological perspective on graduate students of color than the traditional focus on individuals. One of our key findings in looking across Black/African American and Hispanic/Latino engineering and computer science doctorate earners' institutional pathways is the importance of the bachelor's degree institution for subsequent pathways. Students who earn bachelor's degrees from a Top 10 institution are more likely to continue their education at Top 10 institutions for their master's and doctorate degrees; smaller proportions of students attending Top 11–25 or Not Top 25 institutions move into the highest ranked institutions following their bachelor's program.

Using the terminology of Bronfenbrenner, once an individual was within a particular exosystem or macrosystem as determined by broad institutional categorizations, transitioning to a different exosystem or macrosystem did not occur frequently. When we did observe shifts between institutional categories, they tended to occur in the BS-to-MS transition, as opposed to the MS-to-PhD segment of the pathway, which has implications for recruitment efforts. As we extend the analysis to tenure-track/tenured faculty positions, this sample of Black/African American and Hispanic/Latino engineering and computer science doctorate holders demonstrates the infrequency of holding a faculty position at Top 25 institutions if the PhD was not earned at a Top 25 institution—those paths are so small that they are unreportable due to data usage requirements. Again, using Bronfenbrenner's framing, transitioning to different exosystems or macrosystems tended to not occur very frequently for Black/African American and Hispanic/Latino engineering and computer science doctorates.

Institutional prestige, which rankings help operationalize, bakes into the system inequitable access to resources across institutions—this idea may explain why transitions across different exosystems or macrosystems happen infrequently. As the "Matthew Effect" (Merton, 1968) posits, individuals (as well as organizations) who have disproportionate access to resources will continue to benefit from those advantages over time. As Merton noted, "the principle of cumulative advantage operates in many systems of social stratification to produce the same result: the rich get richer at a rate that makes the poor become relatively poorer" (p. 62). Operationalized within the context of institutional pathways, even being able to access undergraduate programs in engineering and computer science varies systematically based on where an individual attends secondary school, which also has systematic connections to race/ethnicity (Knight et al., 2020).

Prior research on undergraduate education broadly has shown that attending prestigious or "elite" undergraduate programs influences college completion, attending graduate school, and labor market outcomes and earnings (Black & Smith, 2006; Dale & Krueger, 2002; Eide et al., 1998; Groen et al., 2007; Hoekstra, 2009; Long, 2008; Melguizo, 2008; Thomas & Zhang, 2005; Zhang, 2005). Extending this logic to the graduate level, attending prestigious graduate programs influences opportunities within graduate school (e.g., likelihood of receiving prestigious awards, such as from NSF's Graduate Research Fellowship) and later career outcomes, such as obtaining academic positions and salary levels (Burris, 2004; Clauset et al., 2015; Posselt & Grodsky, 2017). Because institutional prestige of the doctorate-granting institution matters in hiring processes at other prestigious institutions (Clauset et al., 2015; Pinheiro et al., 2017), our results demonstrate how such inequities in the faculty job market can be partially explained by a stratified educational system that has built-in inequitable access to resources for individuals, which accumulates over time. Pathways can represent systems of privilege, and those with more privilege can move more freely through them. Bronfenbrenner's ecological framework provides the explanation for why institutional environments may reinforce different educational and career pathways for individuals.

Our study shows how such stratification across institutional categories persists throughout graduate and faculty educational and career pathways within engineering and computer science for Black/African American and Hispanic/Latino doctorate earners specifically. We acknowledge that self-selection may account for some—but not all—of the observed trends. For example, Gibbs et al. (2016) showed that racially minoritized men and women in biomedical sciences had lower levels of interest in faculty positions at research-intensive institutions, even after controlling for variables such as scholarly productivity, faculty productivity, career interests at the start of the PhD, and research self-efficacy. However, a prior study using the Survey of Earned Doctorates has shown that racially minoritized STEM doctorate earners experience higher rates of not receiving a job offer at the time of graduation relative to White doctorate earners (Kinoshita et al., 2020). Indeed, our analysis cannot speak to the decision-making processes of individuals, but we can point to some of the implications of a system that appears to be stratified based on where an individual earns a bachelor's degree. Investigating interactions between stratified systems of privilege and individual educational and career decisions would be an important direction for future work that addresses the need for ecological perspectives in the study of doctoral students of color (Flynn et al., 2011; Gibbs et al., 2014).

Our analyses also provide new insights on the extent to which MSIs fit within the institutional pathways of these doctorate earners. The largest proportion of HBCU bachelor's earners will attend a Not Top 25 institution for graduate school, followed by HBCUs, Top 10 institutions, and Top 11–25 institutions—it appears there is room for expanding the graduate pathways from HBCUs into some of the other categories of institutions ranked according to prestige, particularly as doctorate-granting engineering offerings are limited at HBCUs. Many HBCU students attribute at least some of their success to supportive mentoring relationships with their professors, who have been described as having "open door" policies and culturally sensitive and relevant pedagogy (Palmer & Gasman, 2008; Perna et al., 2009; Toldson, 2018). Faculty mentors are aware of students' academic and financial stressors and obligations and help them to achieve balance in order to succeed, a skill that is useful for both undergraduate and graduate studies (Gasman & Nguyen, 2014). Additionally, in contrast to the "weed out" culture common at many PWIs, students at HBCUs value "communal success"; rather than feeling like they need to compete with their peers, students view individual successes as a collective success for the group (Gasman & Nguyen, 2014). Given these factors, it is unsurprising that Black students at HBCUs report "better academic performance, greater social involvement, and higher occupational aspirations" than those at PWIs, as well as strong feelings of acceptance, support, and encouragement (Allen, 1992, p. 39).

Our analysis showcases the importance of HBCU baccalaureate programs as a pathway to support engineering and computer science students' pursuit of a doctorate (Preston, 2017). Using Bronfenbrenner's terminology, the macrosystem, or culture, of HBCUs is important for supporting these goals. However, our results also indicate that paths to the doctorate from HBCUs to highly ranked institutions need to be expanded substantially to impact downstream faculty career prospects—renewed focus should be placed on facilitating these ecological transitions. Another strategy for broadening participation in engineering PhDs would be policy interventions that more equitably distribute resources to HBCUs or lower ranked institutions that can support master's or PhD programs, since they award the majority of doctoral degrees to Black/African American and Hispanic/Latino engineers and computer scientists. Such an approach would reduce the need for an ecological transition between exosystems and/or macrosystems but would instead seek to disrupt the Matthew effect that has been well-documented in higher education.

For HSIs, we observe similar patterns with respect to only small proportions of students accessing highly ranked programs following a BS in an HSI; those paths appear to be deserving of more focus and expansion. A key distinction for HSIs compared with HBCUs, however, is the extent to which an HSI pathway is prominent through the master's and PhD (i.e., more doctorates earn all three degrees from an HSI). Because of different historical definitions, including a decades-long fight for federal funding (Garcia, Núñez, & Sansone, 2019), a growing number of institutions have been attaining HSI status. As national demographic shifts will continue pushing highly ranked institutions toward the HSI distinction, our analyses and the broader literature suggest that the inequities built into the system that are associated with beginning a bachelor's degree at an HSI will likely lessen over time as compared with beginning a doctorate at an HBCU. The focus for HSIs then shifts to *servingness*, or the degree to which the institution supports Latinx students through culturally relevant curriculum and programming, supporting graduate school aspirations, and expanding their social capital (Garcia, Núñez, & Sansone, 2019).

Finally, we intentionally did not impose a citizenship requirement for our analyses. The large proportion of doctorate earners at US institutions who earned a bachelor's degree at a non-US institution was noteworthy for both Black/African American and Hispanic/Latino populations. However, such individuals are often collapsed into a race-less "non-US citizen" or "foreign" category in publications focused on enrollments, such as the American Society for Engineering Education's *Engineering by the Numbers* (Roy, 2019). Discussions of international enrollments in engineering or STEM education more broadly also tend to focus on graduate students from Asian countries because individuals from those geographic regions tend to comprise the majority of non-US engineering graduate students at many institutions (National Science Foundation, 2017). However, our results spotlight how institutional pathways from non-US bachelor's institutions are quite prominent for Black/African American and Hispanic/Latino doctorate earners within engineering and computer science in the United States. Such a finding raises important questions for the ongoing conversation around broadening participation within the field. In line with how we initially framed our paper, diversifying the faculty and the field more broadly was anchored on one premise of addressing historical wrongs and associated inequities within the context of the United States. As we think about educational systems and pathways from this ecological perspective, taking a more global/pan-African/Central and South American view of the issue would push institutions, professional societies, and the field more broadly to reframe the problem and identify possible solutions for diversifying the faculty and field very differently. Our author team does not feel like we are in the position to argue for one approach over another, but our results highlight how traditional methods that mask the race/ethnicity of international doctoral students paint a different picture of educational trajectories—and a different prospective faculty pool—for Black/African American and Hispanic/Latino doctoral students.

6 | IMPLICATIONS

Our study has several implications for future research within the field. First, this analysis demonstrates how the engineering education field can gain unique insights by leveraging large-scale, federally managed data sets. Doing so enabled our team to disaggregate doctoral pathways for specific racial/ethnic groups, which typically must be aggregated into a less specific URM category when data are collected by smaller investigator teams. Second, our results raise questions about the ways in which international students should be treated within engineering education research. By disaggregating the data first by race/ethnicity and then by international student status, we gained new insights about the educational system that we otherwise would have missed. Finally, our research here focuses on structures and overall pathways, but we do not have insights on the ways in which students or prospective faculty members made decisions about those paths. Future research on engineering and computer science doctorate holders can bridge this Bronfenbrenner-informed macro-/exosystem ecological research with a microsystem (i.e., individual) focused research to understand the interplay between structural impacts and individual agency in choosing different educational or career paths for these populations.

The study also has implications for policy and practice. For graduate recruitment, the findings demonstrate that the key transition on which to focus is bachelor's to master's. For "direct-pathway students" who do not take a break following their undergraduate years, highly ranked graduate programs seeking to diversify should consider building meaningful relationships with students at MSIs while they are still undergraduates. Additionally, while much of graduate recruitment focuses on direct-pathway students, some PhD students return to academia after spending some time in the workforce. These "returners" report higher personal, financial, and work–life balance costs than direct-pathway students (Mosyjowski et al., 2017), which should be considered in recruiting efforts. To seriously consider applicants from Not Top 25 institutions and non-US institutions, graduate admissions committees need to reduce reliance on factors such as GRE scores or a student's prior institutional context, and there may be more than one way beyond professional development to enable them to do so. Supports to help students make the ecological transition between different exosystems and macrosystems (i.e., institutional settings) would also be important. Graduate programs at highly ranked institutions should look toward MSIs or Not Top 25 ranked institutions for ideas on how to better support racially minoritized students. Beyond the structural and systemic forces on which our paper focuses, many racially minoritized students choose these educational environments for their supportive institutional climates. While the literature has focused on how institutions aim to mimic "elite" institutions (Cheslock & Knight, 2015; Wall Bortz et al., 2020), learning could also happen in the other direction. Using exosystems and macrosystems that have not been considered as benchmarks to inform practice could potentially be very effective in broadening participation in engineering and computer science graduate education. This learning would necessitate more reciprocal collaborative relationships between institutions that extend well beyond recruiting visits.

As shown in Table 3, Top 10 institutions have similar percentages of Black/African American and Hispanic/Latino PhD earners compared with all PhD earners from these institutions. However, the comparatively lower percentages of Black/African American and Hispanic/Latino PhD earners at the Top 11–25 institutions have important implications for graduate student recruitment. Top 10 institutions often employ the same recruitment strategies: rely on institutional prestige as a selling point of attendance and offer students lucrative fellowships to make their offers more competitive. However, institutions in the Top 11–25 do not have the same financial resources as those in the Top 10 and are unable to compete with those kinds of offers. As Wall Bortz et al. (2020) demonstrated, however, changing strategies away from an arms race of financial offers might actually be a better approach that meets students on their decision-making factors. For example, improving the climate of a program or enhancing student supports within a program can make more of a difference in recruiting students than small increases in graduate student pay. A long-term recruitment strategy of investing in the climate of the department will not only improve the graduate school experience of current students but make programs more attractive to prospective students in ways that money cannot, which has been shown to be the case for all students (Wall Bortz et al., 2020) and minoritized students, more specifically (Wall Bortz et al., 2021). Another important long-term strategy that can help disrupt this lack of mobility between institutions is to change how graduate admissions processes are conducted. As Posselt (2014) argues, faculty admissions committees serve as gatekeepers to programs and prioritize metrics of potential success in graduate school that effectively reproduce the system, which perpetuates disadvantages experienced by minoritized students. Rethinking how admissions decisions are made can be an important step for breaking the institutional mobility logjam.

Similar to graduate student recruitment, our findings have implications for recruiting Black/African American and Hispanic/Latino faculty. A common refrain in faculty searches within engineering and computer science is that the pool of racially minoritized candidates is too small given the competition for such talent across the field. Our findings push back on narratives that “there are not enough qualified candidates of color.” We suggest that institutions ask themselves how they might be ranking their candidates in ways that introduce far too much bias (e.g., prioritizing a candidate's doctoral institution) and/or why large proportions of Black/African American and Hispanic/Latino doctorate earners are drawn to other institutional categories like HBCUs, HSIs, or other Not Top 25 institutions. Discussion of candidates might shift focus to considering past research productivity in institutional context (i.e., for candidates from less-resourced institutions) or potential contributions to the diversity, equity, and inclusion climate of the hiring department. Institutions should critically examine their own faculty search processes as well as the extent to which their work environment is welcoming to and supportive of racially minoritized faculty members. For example, for women of color faculty to thrive, it is crucial that their institutions have supportive faculty colleagues, administrators, and professional societies (McGee et al., 2021). Finally, from a policy perspective with respect to setting broadening participation goals as a field, our findings highlight the need to be specific with respect to what we mean by racial/ethnic diversity as a field—when and how should international students be included as part of that conversation, given that we do not distinguish citizenship status when reporting on the diversity of our engineering faculty? Federal funding sources set a precedent for supporting only students who are citizens and permanent residents, but these data clearly illustrate that an untapped source of Hispanic/Latino and Black/African American engineering faculty are international graduate students. Limiting eligibility of future faculty and graduate traineeship programs to citizens may be yet another way of accumulating competitive advantage for majority faculty candidates.

Tenure-track faculty roles are becoming increasingly scarce in relation to the number of PhD graduates (Larson et al., 2014). Some PhD earners are in faculty positions at teaching-intensive or research-intensive institutions with reduced research activity and few graduate degrees. Advising plays an important role in PhD earners obtaining such positions after graduation. Those with very supportive advisors who were interested in working at research-intensive institutions were more likely to obtain such a position than those with average advisor support (Pinheiro et al., 2017). Conversely, for PhD earners interested in teaching-focused roles, the professional networks of advisors at research-extensive institutions consist mostly of faculty at other research-extensive institutions, and these faculty lacked the connections to help their students obtain positions at top teaching-intensive institutions. Nevertheless, institutional prestige still plays an important role; graduating from a prestigious PhD program leads to an increased likelihood of obtaining a teaching position at a prestigious teaching institution (Pinheiro et al., 2017). An area for future research is investigation into PhD earners' preparation for and transitions into nonacademic careers.

7 | CONCLUSION

The purpose of this paper was to provide empirical data to counter the scarcity fallacy related to prospective PhD students and prospective faculty from traditionally marginalized groups in engineering and computer science. The article demonstrates that broadening participation is not simply a "pipeline" problem, but rather a problem of elitism. It is also, by definition, an issue of systemic racism, as policies that favor graduates from more-resourced (and Whiter) institutions lead to a diminished number of pathways from a Not Top 25 PhD program to a Top 25 tenure-track faculty position for Black/African American and Hispanic/Latino PhD earners. Institutional prestige is grounded in and reproduces structures dominated by elite, White, cisgender men and their values. Rankings such as USNWR, based solely or heavily on peer opinions, are not the measure of quality for which they are widely used in graduate admissions and faculty recruiting—they are better used as a measure of privilege. Given the patterns and data presented here, it is time to more seriously consider applicants from institutions including but not limited to HBCUs, HSIs, other MSIs, and others not ranked among the Top 25, for the assets they bring, not only as role models and for their diversity of perspectives but also for their commitments to justice and community, their perseverance, and their ingenuity in succeeding at institutions with fewer resources. It is up to each of us to fundamentally change how we do admissions and recruiting in engineering; anything less is reproducing the systemic oppression that got us here.

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