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PILLARS OF SUCCESS: THE ROLE OF HISTORICALLY BLACK COLLEGES AND UNIVERSITIES (HBCUs) IN STEM UNDERGRADUATE PREPARATION LEADING TO GRADUATE SCHOOL PATHWAYS

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Historically Black Colleges and Universities (HBCUs) operate and are centered within the nexus of concerted nationwide efforts to advance the participation and success of Black students within the sciences, technology, engineering, and mathematics disciplines (STEM). Through an institution-level asset-based approach, this study aimed to further elucidate how undergraduate STEM preparation and success at HBCUs is linked to the transition into (and experiences within) graduate education. One hundred and fifty-one HBCU alumni from 37 unique HBCUs completed our HBCU Alumni Success survey. Factor analysis revealed 13 emerging components along three main touchpoints along alumni's graduate pathway: their HBCU undergraduate experiences, graduate application, and decision-making, as well as graduate school experiences. Cluster analysis further identified five unique clusters of alumni, revealing variation regarding the individual, institutional, and cultural factors that contributed to HBCU alumni's experiences within their graduate pathway. Specific attributes that characterized each unique cluster included (Cluster 1) experiencing challenges throughout their graduate pathway, (Cluster 2) variation in the sources of motivation that influenced graduate school choice, (Cluster 3) deliberation around attending graduate school, (Cluster 4) high commitment, success, and support in pursuit of a graduate degree, and (Cluster 5) high personal agency as well as faculty and research support within engineering. Implications for practice include capitalizing on the areas of success such as the impact of faculty mentorship and research opportunities.

KEY WORDS: *HBCUs, STEM, graduate pathways, institutional climate, self-determination theory*

1. INTRODUCTION

The growing competitive technological landscape around the world has led to a demand for graduates in science, technology, engineering, and mathematics (STEM) disciplines, as well as an increased emphasis on diversifying the United States (U.S.) STEM workforce. However, more recently, challenges and travel restrictions following the onset of the COVID-19 pandemic have made salient long-standing issues within STEM education and industries. Specifically, systemic factors within higher education continue to impact the pathways of those pursuing STEM careers who have been historically marginalized due to race and/or gender (Toldson, 2019; Gasman et al., 2017). The unsuccessful, and in some cases, lack of, intentional investments within the U.S. continues to serve as a leading factor to the unmet intellectual need for U.S. technological innovation and global competitiveness (Smith et al., 2021; Briggs, 2017). In this paper, we assert that to stay competitive, and more importantly, to broaden participation and access to STEM careers, it is imperative that more Black students enroll in successfully complete STEM graduate programs.

To support the growing diversity, equity, and inclusion (DEI) as well as broadening participation efforts for Black students, a clear understanding of their graduate pathways at various, critical touchpoints along their academic journey is required. The National Academies of Science, Engineering, and Medicine (NASEM, 2019), for instance, have highlighted Historically Black Colleges and Universities (HBCUs) as a key Minority Serving Institution (MSI), and an underutilized resource, in advancing efforts to meet U.S. STEM workforce and educational demands. One aim of this paper is to investigate the underexplored experiences of students at HBCUs who go on to pursue a graduate STEM degree. This aim was motivated by how sources of success that Black students experience during undergrad, particularly at an HBCU, may serve as the foundation that connects them to future career opportunities as scientists, STEM educators, inventors, and innovators.

HBCUs graduate the highest number of Black students who go on to obtain graduate degrees in science and engineering (Upton and Tanenbum, 2014). For this, and many other reasons, we can (and should) look to HBCUs as institutions that champion Black student excellence and inclusion in STEM (McGee, 2020). Student success in STEM at HBCUs is driven by a variety of positive factors including strong student–faculty relationships and overall sense of departmental and institutional belonging on supportive campuses (Esters and Toldson, 2013; Toldson, 2013, 2018; Winkle-Wagner and McCoy, 2018), various STEM initiatives designed to increase undergraduate achievement and retention at these institutions (Palmer et al., 2010), encouragement of students' STEM identity (Morton, 2020), and adoption of asset-based approaches that encourage campus cultures of excellence (Gasman et al., 2017; Winkle-Wagner et al., 2020; Johnson et al., 2020). Even with knowledge of these factors, deeper consideration of the underexplored success of HBCUs, especially in supporting STEM graduate pathways, will allow HBCU leadership and stakeholders to further leverage the current day-to-day activities that have contributed toward their organizational success.

The goal of this paper is to add to existing literature of the success cases of HBCUs, by exploring the experiences of HBCU alumni who have gone on to pursue and earn graduate degrees, with an emphasis on STEM majors. Thus, the research design aimed to uncover success metrics of these HBCUs alumni who have successfully transitioned into, or completed, graduate school (Fletcher et al., 2021). In doing so, the results provide higher education leadership with a greater awareness of the strengths and critical role HBCUs play in promoting Black student success and excellence in route to careers in STEM fields. Specifically, we sought to (1) advance the contemporary telling of the HBCU undergraduate experience as a pillar for graduate success in STEM fields, as well as (2) provide nuance to the complex pathways that have characterized success for these HBCU alumni. To meet the aims of the study, we addressed the following research questions:

1. How have undergraduate HBCU experiences contributed to the graduate pathways of Black HBCU alumni that majored in STEM and who pursued (or completed) graduate degrees?
2. What differences are there among HBCU alumni regarding the individual, institutional, and cultural factors that contributed to their experiences within their graduate pathway?

2. LITERATURE REVIEW

The following sections draw from the extant literature to contextualize the connections between (1) the role of HBCUs in diversifying the STEM disciplines, (2) the factors central to undergraduate HBCU experiences that reinforce STEM student success, and (3) how HBCUs have prepared students to enter their respective graduate pathways. Additional information on aspects of graduate school choice among Black students is also shared to address the current gaps in the literature on how HBCU students successfully transition into graduate school (and the variation in experiences), which this project aims to fill.

2.1 Diversifying the STEM Disciplines through HBCUs

Historically Black Colleges and Universities (HBCUs) operate and are centered within the nexus of concerted nationwide efforts to advance the participation and success of Black students within STEM fields. More recently, the National Academies of Science, Engineering, and Medicine (NASEM) in their report *Minority Serving Institutions: American's Underutilized Resource for Strengthening the STEM Workforce* (2019), further spotlighted HBCUs as bastions of Black student academic success and excellence. Overall, the critical role HBCUs play in advancing broadening participation efforts for Black students in the STEM disciplines is well documented (Palmer et al., 2010; Owens et al., 2012; Jett, 2013; Upton and Tanenbum, 2014; Forbes, 2016; Gasman et al., 2017b; Toldson, 2018, 2019; Cain et al., 2018; Wilson-Kennedy et al., 2018; McGee, 2020; Smith et al., 2021; Umerah et al., 2021; Aycock et al., 2022). However, linking together

how HBCU undergraduate experiences provides the foundation for Black collegians to pursue STEM graduate pathways remains largely underexplored.

Taking an institutional-level, asset-based approach that emphasizes the long-standing strengths and achievements of HBCUs can lend tremendous insight in addressing this gap (Williams et al., 2019). This perspective is relevant when considering success cases of HBCU alumni who pursue graduate work, yet whose empowering HBCU undergraduate experiences may be ignored as the key foundation for their graduate success (Crewe, 2017). This marginalization of the HBCU experience as foundational to graduate success results from persistent negative stereotyping and deficit-oriented thinking (themselves manifestations of structural racism; McGee and Bentley, 2017) around the value and relevance of HBCUs in higher education (Bettez and Suggs, 2012). However, educational statistics consistently demonstrate HBCUs' track record in championing Black student academic and professional success. For example, HBCUs' campus climate, which is inclusive and empowering of Black identity, coupled with a multiplicity of best practices lead HBCUs to outperform non-HBCUs in servicing first-generation (52% of HBCU students) and Pell-eligible students (75% of HBCU students). The enormity of these commitments and achievements are underscored by the fact HBCUs represent 3% of all U.S. colleges and universities yet educate approximately 10% of Black college students and award 17% of the bachelor's degrees earned among all Black graduates (Owens and Njoku, 2021).

The disproportionate impact of HBCUs to successfully prepare and transition their students is immediately apparent when considering that approximately a third of Black STEM PhD recipients received their undergraduate education at an HBCU (Upton and Tanenbum, 2014). In fact, HBCUs graduate almost 20% of all Black engineers while only making up less than 1% of ABET accredited institutions (Fletcher et al., 2021). Moreover, HBCUs also graduate a disproportionately large percentage of Black STEM PhDs from their doctoral programs even though only a small fraction of HBCUs offer these graduate programs (Rice et al., 2016). These findings set HBCUs apart as leaders on the forefront of promoting a more diverse and inclusive STEM workforce in the U.S. (Flowers, 2013; Toldson, 2019; McGee, 2020).

Taken together, undergraduate HBCU experiences are central to graduate pathway narratives and our understanding of the academic journeys that promote and produce Black professional excellence in STEM. This is especially relevant as the U.S. Census Bureau projects that, by 2044, most Americans will belong to a minority group, with roughly 20% of the American population estimated to be foreign-born by 2060 (Colby and Ortman, 2015). Moreover, the proportion of Black, foreign-born, bachelors' and advanced degree holders in the U.S. has grown rapidly since 2000 (from 21% to 31% of those 25 and over), outpacing the growth of the overall U.S. and foreign-born populations (Tamir and Anderson, 2022). Additionally, recent research has noted how citizenship status can influence college experiences for engineering/STEM undergraduates at HBCUs (Burrell et al., 2015; George Mwangi et al., 2016), including the role of family support and community in strengthening Black international student success within STEM (Onuma et al., 2022). Taken together, this emphasizes the need to turn to MSIs,

and in this case, HBCUs, as institutional leaders in preparing Black students for STEM careers and whose insights and best practices will help further prepare all institutions as we experience increasing diversity in U.S. (as well as U.S. higher education) demographics.

2.2 Undergraduate HBCU Experiences and STEM Success

Black students from all over the country make the decision to attend an HBCU for their undergraduate educations for a variety of reasons (Robinson, 2020). Some motivations borne out from the literature include continuing the legacy of HBCU alumni within their family, being immersed in an academic environment that champions Black excellence, and even finding respite from the racial battle fatigue experienced during their K-12 education (Johnson, 2019). More recently, Black college-bound students have increasingly considered how the current racial climate of the U.S. weighs into their decision to attend an HBCU for their undergraduate experience (Williams et al., 2021)—and rightfully so, as recent research has reported how racial biases can manifest within and impact the quality of higher education spaces (Williams et al., 2019; Williams and Toldson, 2020). In fact, a study conducted by Williams and colleagues (2021) found that a constellation of interconnected factors related to (1) racial microaggressions experienced in high school tied to revelations about White peers' political views under the Trump administration, (2) concerns of physical safety on a PWI campus, and (3) interest in occupying culturally and racially affirming spaces of HBCUs all weighted heavily in Black students' decisions to attend an HBCU from 2016–2018. Moreover, these factors contribute to a surge in enrollment for HBCUs in the face of recent racial injustices, discrimination, and prejudice (Williams and Palmer, 2019). The celebration and exploration of Blackness in all its expressions and complexities is not new to the HBCU undergraduate landscape and has been an essential component in shaping the pedagogical practices students enjoy at HBCU campuses (Toldson, 2018, 2019). More specifically, the nuance and unique strengths of what powers HBCU undergraduate experiences are perfectly captured by Williams and colleagues (2021) observation regarding HBCUs' "*... emphasis on culturally relevant knowledge and culturally-informed pedagogy that centers Black experiences; and their commitment to Black cultural validation via connecting with Black communities and Black students' backgrounds*" (p. 1).

By contextualizing course curricula and higher education practices as rooted within Black scholarship and Black socio-political and cultural issues, HBCU students are afforded safe spaces to explore their cultural identity, embrace and express their own Blackness, and feel that their authentic sense of self is supported and not marginalized (Morton, 2020; Williams et al., 2021; Freeman et al., 2021; Williams and Taylor, 2022). In doing so, HBCUs provide educational and classroom environments that counter predominant deficit-based perspectives regarding Black collegians and honor the lived experiences and racial identity of their Black college students (Ginsberg et al., 2020; Owens and Njoku, 2021). Examples include culturally informed and asset-based coursework, research, and other university experiences. In the context of biomedical

departments at HBCUs, one such academic example emphasized student preparation with the physical and mental health challenges (e.g., COVID-19 complications tied to limited access to healthcare and disproportionate employment in at-risk jobs) within society that currently and disproportionately affect Black lives (Duque, 2021; Smith et al., 2021; Aycock et al., 2022).

The cultural relevance and affirming approaches to HBCU pedagogy and research opportunities are also noted to have positive consequences on strengthening STEM identity development (Smith et al., 2019; Morton, 2020; Williams and Taylor, 2022). In fact, Rockcliffe (2020) found that Black women majoring in engineering at HBCUs reported significantly higher scores of engineering identity and academic self-efficacy than their non-HBCU counterparts, who also reported greater incidents of racial micro-aggressions. This latter finding is of note, as microaggressions, such as stereotype threat related to race and/or gender, can place constraints on STEM identity development for students at any institution (McKoy et al., 2020), so the safe space provided for Black women at many HBCUs to explore and embrace their racial and cultural identities is of direct benefit to their undergraduates' STEM success. For example, Spelman College represents an institution, and community, that champions Black women's excellence and success in science and technology through their asset-based practices, commitments, and leadership of faculty and staff (Johnson et al., 2020; Winkle-Wagner et al., 2020). As Okonkwo (2015, p. 2) notes:

> *What makes the community at Spelman College special is a sense of community that begins with the historical, cultural, and lived experiences of African American women. The story of the institution is told through the legacies of women who perceive their own backgrounds as the locus of their power, despite what others may believe. Today, what is means to be a scientist at Spelman – a Spelman Woman in science and technology, is a woman who dares to confront notions and expectations that say she could not (Okonkwo, 2015, p. 2).*

Furthermore, faculty and the personal-touch mentorship they provide are another core strength of HBCUs, which are the vehicles for implementing the culturally informed pedagogy discussed earlier. That is, faculty mentorship and guidance has been a well-documented factor contributing to STEM success for HBCU undergraduates (Jett, 2013; Gasman et al., 2017; McCoy et al., 2017; Toldson, 2018, 2019; Smith et al., 2021; Williams et al., 2021; Aycock et al., 2022). Faculty mentors at HBCUs are often described as having a very positive and encouraging impact on their STEM students to pursue their passions within their major (Palmer and Gasman, 2008; Forbes, 2016; McCoy et al., 2017). Recent research found that first-year STEM majors at HBCUs identified the nurturing, family-like interactions with faculty in addition to teaching approaches utilizing racial socialization (i.e., giving deeper meaning and exploration to one's positionality as a Black person in America and how to thrive given the racialized structure and systems embedded in American society) as factors that motivated their continued commitment to their STEM major (Freeman et al., 2021).

HBCUs' utilization of administrative and faculty leadership plays a vital role in the success of HBCUs overall and the STEM students they serve (Savage, 2017; Williams et al., 2021). These impactful student–faculty relationships, personal-touch mentoring, and culturally relevant pedagogic practices implemented by HBCU leadership provide an overall sense of belonging that contributes to the supportive, affirming atmosphere of these campuses (Toldson, 2018; Winkle-Wagner and McCoy, 2018). Taken together, the strengths of HBCUs continue to persist even when considering systemic challenges and barriers to achieving resource equity, including chronic underfunding (Commodore and Owens, 2018; Harper, 2020; Quilantan, 2020) that contributes to institution-level disparities in funding from the federal government between HBCUs and non-HBCUs. These systemic inequities exacerbate limitations on HBCUs to leverage increased research productivity as an opportunity pathway for undergraduates to engage in STEM spaces (Toldson, 2019).

Although these systemic barriers of inequity that place constraint on HBCUs have existed historically and pre-pandemic, administrative and faculty leadership at HBCUs have continued to provide effective support to STEM students well after the onset of the COVID-19 pandemic (Fletcher et al., 2022). For example, our previous research found that engineering undergraduate students reported largely positive interactions and continued support from their engineering faculty and mentors following the transition to virtual instruction at their respective HBCU (Fletcher et al., 2022). Additionally, during re-population efforts to reopen campuses, HBCUs demonstrated early and sustained success, while also experiencing comparatively fewer infection cases than non-HBCUs institutions stemming from practical strategies to protect their stakeholders (Murty and Payne, 2021; Porter and Holquist, 2021). These practices within STEM spaces, and in response to global emergencies, highlight the actions taken by HBCU leadership, which have been critical in advancing diversity in higher education despite continued underrepresentation in many STEM fields, particularly engineering (Fletcher et al., 2021).

Finally, an additional factor HBCUs successfully leverage in supporting their students is undergraduate STEM research initiatives and programs (Palmer et al., 2010; Morton, 2020), which impact STEM persistence and graduate school choice (Fakayode et al., 2014; Gasman and Nguyen, 2014; Adida et al., 2020). For example, STEM enrichment programs such as the Research Initiative for Scientific Enhancement (RISE), allow HBCUs to engage their students in research practices that positively impact their undergraduate experiences as well as encourage them to major in and successfully graduate from STEM disciplines (Umerah et al., 2021). Initiatives, such as Xavier University's NIH-funded Research Center in Minority Institutions (RCMI) program, provide opportunities for students to engage with research regarding cancer and health disparities (Smith et al., 2021), whereas Howard West, a satellite campus of Howard University located at Google's headquarters, connects IT and engineering undergraduates with top tech professionals and mentors (Cain et al., 2018). These undergraduate experiences create safe spaces for HBCU students to develop a strong, internalized sense of self-confidence and well-being as STEM research practitioners (Walker and Goings, 2017). Additionally, alumni can also leverage the strength and knowledge cultivated from their

undergraduate experiences to navigate or avoid the uncomfortable challenges that may arise in less diverse workplaces (Walker and Goings, 2017).

2.3 Graduate Pathways

There is a multiplicity of intrinsic and extrinsic factors that influence decision-making experiences for Black students in preparation to pursue graduate education (Collins, 2012; McCallum, 2015, 2016, 2017, 2020; Lewis et al., 2017). For example, Collins (2012) revealed that factors such as receiving financial aid, as well as benefits of cultural capital (i.e., parental education level), positively influence Black student access and participation in applying to graduate programs. Additionally, recent research by McCallum (2016, 2017, 2020) has indicated that various internal motivations drive Black students' decisions to enroll in doctoral programs. For example, McCallum (2016, p. 54) highlighted the role of family in providing "*insight, resources, and emotional and social support*" when engaging in the early decision-making processes involved with entering graduate education. Moreover, Black doctoral students have noted how their motivation to earn an advanced degree was supported by a desire to honor their communities and families by breaking through the barriers and systems of oppression that prevented family members before them from participating in higher education (McCallum, 2016, 2017; Lewis et al., 2017; Yi and Ramos, 2021). Themes of commitment to equity and social justice drive motivation among Black doctoral earners (McCallum, 2017; Lewis et al., 2017) has also been recently noted by Yi and Ramos (2021, p. 9), who found that the Black women pursuing doctoral education indicated that their advanced degree would allow them "*access to spaces and contexts where they would then be able to advocate for their community's needs.*" Additionally, receiving mentorship from educational leaders that practice "othermothering" (McCallum, 2020) is also important in encouraging Black students to access and pursue graduate pathways. These connections with faculty represent deep and holistic caring dynamics that feature elements of "keeping it real" regarding their mentorship approach, which ensures the academic success and well-being of the student (McCallum, 2020).

Black undergraduate students' scholarly experiences also inform their motivation to pursue and obtain a graduate degree (Lewis et al., 2017). Within STEM, participating in summer research experiences and fellowship programs during undergrad served as significant determinants of whether Black students would continue and persist into STEM fields post-graduation (DePass and Chubin, 2008; Adida, 2020; May and Chubin, 2003). For example, Black men in pursuit of an advanced engineering degree have credited experiences with programs such as the Meyerhoff Scholars Program, Research Experience for Undergraduates (REU), and Summer Research Opportunity Programs (SROP) as playing a critical role in bridging their undergraduate experiences into successful graduate pathways (Henderson et al., 2021). Burt et al. (2020) note that desires to be a successful engineer also influence graduate school decisions and persistence following enrollment for Black men, which is consistent with ad-

ditional findings emphasizing Black students' graduate school motivations are also driven by the career benefits associated with obtaining an advance degree in engineering (Henderson et al., 2021) along with investing in one's own future success and intellectual curiosity (Lewis et al., 2017).

Considering recent progress taken in understanding the factors that influence graduate school choice and motivation to pursue and advanced degree among Black students nationally, there remains a gap in the literature concerning the experiences of HBCU students (Strayhorn et al., 2013), especially those in STEM (Preston, 2017; Fletcher et al., 2021). Thus, our study aims to address this gap via deeper exploration of how HBCU experiences contributed to the graduate school decision-making and pathways of HBCU alumni who pursued graduate degrees in STEM disciplines. The research will also consider the differences among these HBCU alumni along their academic journeys, as their experiences are not monolithic.

3. PURPOSE

HBCUs have played a critical role in the production of African American and Black students who obtain STEM degrees, especially within engineering. This study provides the broader research community with knowledge directly from HBCU alumni on how and why HBCUs have been so successful with matriculating Black students into graduate STEM programs, such as in engineering and computing. More broadly, institutional stakeholders at HBCUs, stakeholders at PWIs and other MSIs, who strive to increase enrollment and persistence numbers for Black students in STEM, can utilize the findings presented herein in supporting their students. Lastly, this study shares evidence-based insights and recommendations to contribute to the goals outlined by NASEM (2019) including (1) increasing underrepresented minority students' interest in graduate STEM degrees, (2) retaining and graduating Black students in those programs, and (3) documenting best practices.

4. THEORETICAL FOUNDATION

Given the critical role that HBCUs have played for Black alumni pursuing STEM graduate degrees, we leveraged theoretical foundations that would enable us to examine different factors that may affect an individual's pursuit of graduate education: (1) their goals and motivations, and (2) their experiences in their undergraduate education. We leveraged Self-Determination Theory (Ryan and Deci, 2000a,b) to capture the individual factors that shape a Black HBCU undergraduate student's pathway to and through graduate education. To characterize the impact of a student's experiences in their undergraduate education, we used two complementary frameworks: institutional climate for racial and ethnic diversity (Hurtado et al., 2012) and African American and Black students' perceptions of their campus culture (Brown et al., 2004, 2005). The first framework allowed us to consider systemic factors of an institutional climate, while the second provided a focus on students' perceptions of their campus culture.

Self-determination theory (Ryan and Deci, 2000a,b) has three dimensions: competence, autonomy, and relatedness. In the case of graduate school preparation, competence could be described as a student's perception that they have the necessary knowledge to succeed in graduate school and/or to be admitted to graduate school. Relatedness captures an individual's feeling of connectedness to a community, which could describe a student's connectedness to their discipline, their peers applying to graduate school, and/or their faculty who may be graduate student advisors. Lastly, autonomy represents the perception that an individual has control over their decisions. Within graduate school preparation, a student's autonomy may be impacted by, for example, their perception that the graduate school application provides them sufficient opportunities to express themselves and their abilities.

To further understand the relatedness dimension, specifically in the context of the student's experience at an HBCU, we integrated two frameworks that focus on institutional climate and culture. The first was Hurtado and colleagues' institutional climate framework, which was originally developed based on qualitative and quantitative research about the experiences of racial and ethnic groups within higher education (Hurtado et al., 1999, 2008; Hurtado, 1994; Yi, 2008), the framework expresses institutional climate using five dimensions (Hurtado et al., 2012): historical, organizational, compositional, psychological, and behavioral. The historical dimension explores an institution's legacy and its influence on "current campus climate and practices" (Hurtado et al., 2012, p. 58). The organizational dimension considers those structures and processes that exist within an institution that may have unforeseen effects on individuals or groups, while the compositional dimension uses objective measures (e.g., size, selectivity) to characterize social and ethnic groups. The psychological dimension illustrates "an individual's perception of institutional responsiveness" to the issue being explored (Yi, 2008, p. 165). Finally, the behavioral dimension describes "the context, frequency, and quality of [social] interactions" across groups within an institution (Hurtado et al., 2012, p. 66).

While Hurtado and colleagues' framing of institutional climate provides a broad, systems-level characterization of factors affecting a student's experience at an institution, we needed an additional framework to help us further deconstruct the dimension of relatedness from self-determination theory. Specifically, how did these HBCU alumni perceive their interactions and overall relatedness to their campus community? To address this question, we borrowed from Brown and colleagues' existing explorations of African American and Black engineering students' perceptions of their campus culture (Brown et al., 2004, 2005). In these studies, campus culture considered (1) classroom experiences, (2) faculty-staff relationship, (3) institutional support services, (4) peer interactions, (5) student effort to learn, (6) goal development and management, and (7) institutional commitment. The use of these two climate and culture frameworks allows us to ground our data collection approach in a rich characterization of a student's undergraduate environment and provide a helpful framework for uncovering ways in which institutional climate can impact how a Black HBCU undergraduate student navigates their postgraduate planning and decision-making (see Fig. 1). Taken with self-determination theory, these theoretical foundations enabled us to capture the internal and

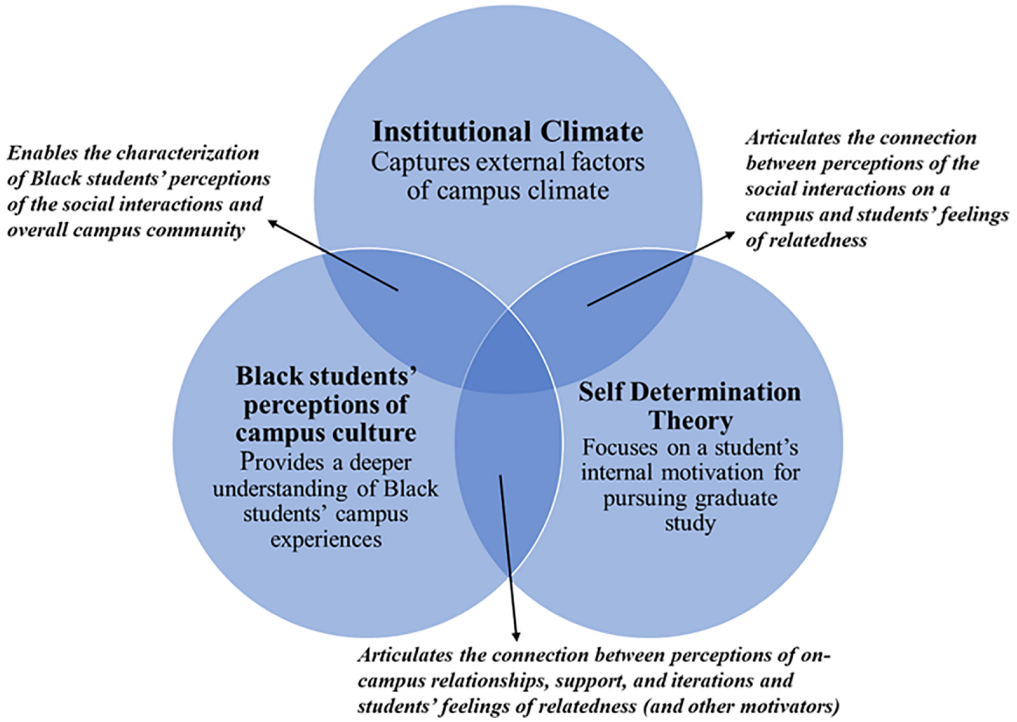

FIG. 1: Intersections of each framework's contributions that shape the overall theoretical foundations for the study, allowing for an exploration of Black students' perceptions, behavioral dimensions, and external factors of campus climates

external factors impacting these Black HBCU undergraduate students as they consider and pursue graduate study.

5. METHOD

This study sought to address two research questions: (1) *How have undergraduate HBCU experiences contributed to the graduate pathways of Black HBCU alumni that majored in STEM and who pursued (or completed) graduate degrees?* And (2) *What differences are there among HBCU alumni regarding the individual, institutional, and cultural factors that contributed to their experiences within their graduate pathway?* To answer these questions, we developed the HBCU Alumni Success Survey, which was disseminated to HBCU alumni across multiple platforms and mediums. First, factor analysis was used to assess validity of the developed survey and to identify the factors that affect the graduate pathways. Then, factors extracted by factor analysis were used as input variables in the cluster analysis to identify groupings among survey respondents across the factors having impact on their graduate pathways. Cluster analysis is the technique to summarize data sets in terms of a small group or clusters based on proximity refers to similarity, dissimilarity, or distance (Landau et al., 2011).

5.1 HBCU Alumni Success Survey

Survey development was informed by the theoretical foundations, relevant literature on student success and institutional culture, existing climate instruments (Brown et al., 2004, 2005; Hurtado et al., 2008; Godwin, 2016; Walton and Liles, 2018; Lee et al., 2019), as well as our instrument validation process (Fletcher et al., 2021). The latter process was achieved via a subject matter expert review conducted by the advisory board overseeing the research presented in this manuscript, pilot item testing with discipline-based education researchers, and a cognitive interview (Willis, 2004) with an advisory board member. Fletcher et al. (2021) provides a detailed overview of the different components of the survey development process.

The HBCU alumni success survey was designed to uncover success metrics of Black students that majored in STEM at HBCUs and have successfully transitioned into, or completed, graduate school. The final survey included 45 items distributed across three main blocks: (1) *Undergraduate Experience*, (2) *Graduate School Applications and Decisions*, and (3) *Graduate Experience*. Summary details of the survey are shared in Table A1 (see the appendix of Fletcher et al., 2021) for complete listing of items featured in each of the main blocks. The responses on the survey required a response on a 7-point scale (1 = strongly disagree, to 7 = strongly agree) and the directionality of the scale was dependent on the wording of the question. The pilot and final surveys were distributed using Qualtrics (https://www.qualtrics.com). The survey took approximately 20 minutes to complete. As shown in Table A1, each block of the *Undergraduate block and Graduate Experience block* among HBCU alumni success survey showed very good internal consistency with greater than 0.80 (Taber, 2017). However, *Graduate School Applications and Decisions* block was slightly under but very close to 0.70, having an acceptable range greater than 0.60 (Hair Jr. et al., 2003).

5.2 Procedures

5.2.1 Recruitment

Three social media platforms (including flyer and accompanying tiny URL link) were used to reach the broader HBCU community (i.e., Twitter, Facebook, and LinkedIn). These social media platforms were targeted due to recent research indicating increased use in these websites in access information, indicating that virtual outreach may provide increased chances for higher response rates (Woods and Shelton, 2019). In particular, the Twitter account, @STEMatHBCUs, was created as an outlet for survey outreach as well as to supplement our additional email outreach, especially given the current COVID-19 pandemic. Our Twitter blast recruitment strategy was centered in reaching out directly to HBCU Twitter accounts (and affiliated accounts) as well as HBCU national alumni chapter accounts. The survey was distributed via social media and email from November 2020 to February 2021.

Snowball sampling was also used to increase participation, as HBCU (particularly alumni) connections were essential in reaching the target audience. Emails were sent to the following academic populations to solicit participation: (1) institutional leaders (e.g., Deans, Provosts, Presidents); (2) HBCU alumni office leadership; and (3) STEM departmental leadership (with focus on connecting with engineering chairs and faculty). Additional email outreach was conducted to reach out to the HBCU chapters of National Pan-Hellenic Greek Organizations due to their extensive networks and strong connections maintained with alumni.

5.2.2 Data Collection

Prior to data collection, the Institutional Review Board (IRB) at Florida International University approved the current project (IRB no. 107986). Participants were informed that the purpose of the study was to

> *'... investigate the sources and metrics of success for HBCU students in STEM programs, their academic experiences, and understanding the successful transition of applying to and attending graduate school. Additional questions also seek to explore the relationship between students' personal identities and their academic journey from undergraduate to graduate school.'*

Each participant was asked to complete a survey which included demographic questions, as well as items about their educational experiences and academic success, which were both personal and HBCU related. No identifying information was requested. No participants received any compensation for completing the survey.

5.2.3 Participants

A total of 151 HBCU alumni from 37 unique HBCUs completed the survey. Most participants reported they were female-identifying (58%) as well as identifying as African American or Black (99%). Similarly, most participants reported that they had received their undergraduate bachelor's degree in a STEM department (83%), with 41% from an engineering discipline. Table A2 outlines additional demographics for participants.

5.2.4 Data Analysis

The IBM Statistical Package for Social Sciences (SPSS) and R were used to analyze all the resulting data. After data cleaning was completed (e.g., coding variables, accounting for missing data), preliminary analyses were performed, including factor and cluster analysis on the complete data set as well as on a data set with outliers removed at the univariate and multivariate level. A principal component analysis (PCA) with varimax rotation method was conducted for each survey block. Once factors were finalized, the factor scores for the participants were calculated by averaging their scores on survey

items within the factor. The factor scores were then used as the inputs in the cluster analysis. An agglomerative hierarchical clustering algorithm was utilized using Ward's minimum-variance method and squared Euclidean distances. To determine the optimal number of clusters, various ways including dendrogram, silhouette coefficient, and gap statistics were used as an internal validity of clusters. Lastly, a Kruskall-Wallis's test was utilized to examine the validity of clusters with external criteria. All statistical analyses were performed with an alpha level designated at 0.05.

5.2.5 Authors' Positionalities

The research team who collectively and collaboratively developed, implemented, and analyzed this project as well as produced its resulting manuscript are all individuals whose research interests and scholarly work focus on diversity, equity, and inclusion within engineering education and STEM, more broadly. The two co-first authors served as postdoctoral associates for the third author, an HBCU alumna, who jointly with the fourth author have received NSF funding to investigate student academic success at Historically Black Colleges and Universities (HBCUs), with a continued commitment to expanding their research in this space. One co-first author identifies as a White man with a STEM undergraduate and graduate education from two Minority Serving Institutions (HSI and AANAPISI and emerging HIS, respectively). The author acknowledges that his experiences as a first-generation, Pell-eligible student grant him access to spaces mutually shared by many HBCU students; however, his intersecting and privileged racial and gender identities place him as an outsider to the lived experiences shared by many of the HBCU students represented within this research. This author leverages his emersion as a postdoctoral researcher invested in HBCU student and institutional success as well as authentic partnership with HBCU mentors, colleagues, and alumni to help minimize blind spots and limitations in interpretation. The other co-first author identifies as an Asian woman and has a dual professional background: educational psychology and quantitative methodology. This author connected her substantial research interests of students' well-being and academic success with her rigorous statistical knowledge in conducting the current study. The author's experience as an underrepresented minority group member and professional experiences as a postdoctoral associate conducting research focused on supporting HBCU student success were woven in understanding the experiences of HBCU students pursuing graduate pathways. Two of the six authors are graduates of HBCUs. Additionally, five of the six authors identify as women of color with three identifying as Black or African American women.

5.2.6 Protection of Vulnerable Populations

This manuscript did not target a vulnerable participant population. However, this manuscript does focus on the undergraduate and graduate pathway experiences of HBCU alumni that self-identified with social identities (i.e., race and gender) that have been historically marginalized within higher education systems. This is reflected in many of our

participants identifying as Black or African American (99%) as well as women (58%). To protect participants within this study, no identifying information was requested as part of our survey design. Additionally, the findings of this study are reported from data at the aggregate level. There are no reported outcomes of an individual's experience or that of a single, specific HBCU. To this end, no one participant or institution can be made identifiable from our reported findings.

6. RESULTS AND DISCUSSION

The overall results of the survey analysis are five clusters that illustrate the contribution of the undergraduate HBCU experiences to the graduate pathways of Black HBCU alumni (Research Question #1) and the distinct experiences of HBCU alumni within their undergraduate experience, decision to pursue and apply to graduate school, and within their graduate experience. The differences across the clusters highlight the individual, institutional, and cultural factors that influenced the experience of HBCU alumni and their overall graduate pathway (Research Question #2). To illustrate the results, this section begins by reviewing the factor analysis of survey items as well as the cluster analysis that followed. Immediately after, each of the five clusters is introduced and described.

6.1 Factor Analysis

The principal component analysis (PCA) with varimax rotation method was conducted. Within each survey block, we leveraged the theoretical foundations to make sense of the resulting factors. Regarding the *Undergraduate Experience* block, three factors explaining 50.84% of the variance were extracted. The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.80, indicating good adequacy. Bartlett's test of sphericity was significant [χ^2 (105) = 555.20, $p < 0.001$] and there were no items whose variance inflation factors (VIFs) were greater than three, indicating there was no multicollinearity issue. Table A3(a) includes each factor and corresponding items for the *Undergraduate Experience* block. Component one stands for *faculty mentorship*, component two for *HBCU support system and student success*, and component three for *HBCU student empowerment*. Two items from our second component were removed due to a cross-loading greater than 0.30 and no strong loading on a focal factor [see Table A3(a)].

For the *Graduate School Applications and Decisions* block, six factors explaining 62.01% of the variance were extracted. The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.64, indicating acceptable adequacy. Bartlett's test of sphericity was significant [χ^2 (153) = 589.10, $p < 0.001$] and there were no items whose VIFs were greater than three, indicating there was no multicollinearity issue. Table A3(b) shows each factor and corresponding items for the graduate school applications and decisions block. Component one represents *faculty and research influences*, component two for *family influences*, component three for *peer influences*, component four for *conflicting commitments and choice*, component five for *prioritizing access*, and component six for

program reputation and choice. Three items were removed due to cross-loading greater than 0.30 and no strong loading on a focal factor [see Table A3(b)].

Within the *Graduate Experience* block, four factors explaining 68.66% of the variance were extracted. The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.78, indicating good adequacy. Bartlett's test of sphericity was significant [χ^2 (66) = 624.70, $p < 0.001$] and there were no items whose VIFs were greater than three, indicating there was no multicollinearity issue. Component one stands for *HBCU undergraduate preparation for graduate success*, component two for *graduated student confidence*, component three for *graduate researcher identity development*, and component four for *graduate student satisfaction* [see Table A3(c)].

6.2 Cluster Analysis

6.2.1 Determining the Number of Clusters

To determine the optimal number of clusters, various ways including the dendrogram, silhouette coefficient, and gap statistics were used as an internal validity of clusters. The average of the silhouette width coefficient was highest in the five-clustering solution, while its coefficient was less than 0.20. Additionally, the result of the gap statistic and dendrogram supported five clustering solutions. Therefore, five clusters were selected in this study.

Kruskall-Wallis's test was utilized to verify the selected clusters using group comparison. As shown in Table A4, five clusters were significantly different on each factor (i.e., *mentorship, support, research, family, commitment, access, peer, reputation, preparation, confidence, identity,* and *satisfaction*) except *empowerment*. Also, a Kruskall-Wallis test was utilized to examine the validity of clusters on the selected external items which were not used in the cluster analysis. As shown in Table A5, five clusters showed statistically significant difference on the following items: "Overall, faculty members encouraged me to make connections with my classmates," "My student peers encouraged me to apply to graduate school," "My decision to apply to graduate school was positively influenced by my experiences with STEM-related organizations." Therefore, clusters extracted performed properly by providing significant group differences on most variables.

6.3 Cluster Descriptions and Discussion

The resulting five clusters ranged in size from 10 to 47 individuals within each cluster (see Tables A6 and A7). While these clusters each present a uniquely different profile of the factors contributing to a student's graduate school pathway, there were also similarities across the clusters. From these similarities, two critical insights emerged. First, the findings across all clusters suggest that the HBCU experience empowered these HBCU alumni. Second, the perceptions of mentorship and support provided during an HBCU undergraduate experience were highly positive across all five clusters. In other words,

the HBCU experience contributed to the graduate pathway of these HBCU alumni by empowering and supporting them during their undergraduate experience.

Overall, the differences among the five clusters focus on transitions into graduate school, influences on their decision to pursue graduate school, and researcher identity development. Each cluster will be explored in depth in the subsequent sections. As a reminder, the responses were scored on a 1 to 7 scale, where 1 indicated strongly disagree and 7 indicated strongly agree.

6.3.1 Cluster 1: Pathway Challenges into, during, and Out of Graduate School (n = 14)

The first cluster comprised HBCU alumni committed to attending graduate school (M = 5.07, SD = 0.85). Yet, their transition into, during, and out of graduate school illustrated that the pathway was not smooth. For example, within their undergraduate experience, the evidence of preparation for graduate school was inconsistent across the alumni (M = 4.33, SD = 1.1) and items regarding the development of a researcher identity yielded the second lowest mean among clusters (M = 5.59, SD = 0.94). This cluster also had the lowest mean for perceived support from academic support services during their HBCU experience (M = 5.27, SD = 0.88). Overall, their transition into graduate school was more challenging than their peers as evidenced by their lower confidence in their abilities during their first year (M = 3.17, SD = 1.1). These factors demonstrate factors within the transition that may have impacted these HBCU alumni's perceptions of their own competency as researchers and graduate students. This lower level of perceived competency could have affected their motivation to pursue graduate school and their overall experience. For example, Wofford (2021) demonstrated in their study of undergraduate computing majors how psychosocial factors, such as lower perceptions of academic ability and self-efficacy, were tied to lower self-confidence in admission into graduate computing programs for women and students of Color. For this cluster, the data show their satisfaction with, and the decision to attend, graduate school was mixed (M = 4.71, SD = 1.31), with challenges surrounding psychosocial factors related to their self-perceptions potentially playing a role in this finding.

When considering the graduate institutions attended by alumni, 80% were public and over 90% were characterized as a PWI. This breakdown of institution type along with the mixed satisfaction in their decision to attend graduate school aligns with literature around Black students' challenges at PWIs during graduate degree programs (Grant and Ghee, 2015). Most of these alumni within this cluster received an undergraduate degree in a non-engineering, STEM discipline. The graduate degrees completed among this group show the most diversity with one participant earning a law degree, one medical degree, five STEM master's degree, and six STEM doctoral degrees. Lastly, the majority of the HBCU alumni in this cluster had families who had graduated from college (71.4%). While previous research (e.g., Collins, 2012) emphasizes the important role of parental education level in HBCU students' graduate pathways, it may be that the diver-

sity of graduate degree pathways or other factors may have affected the extent to which family played a role in their experiences.

6.3.2 Cluster 2: Variation in Factors Influencing Graduate School Choice (n = 34)

This cluster is characterized most distinctly by factors influencing the HBCU alumni's decision to pursue a graduate degree, which did not include the more common influences including peers, faculty, and research experiences. In particular, the roles of faculty and research experiences in their decision-making were mixed and the lowest mean among the clusters (M = 5.01, SD = 1.07). Peers were also not a strong source of influence on the alumni in this cluster (M = 4.57, SD = 0.79). Similar to other clusters, familial influence was also not as prevalent. Across their undergraduate and graduate research experiences, these alumni demonstrated some development of a research identity, but not as strong as other clusters (M = 4.57, SD = 1.01). With these influences in mind, these alumni had more doubts about deciding whether to apply to a graduate program than many of the other clusters (M = 3.91, SD = 1.22).

Peer, faculty, and research opportunities do play a major role in the decision-making process around graduate school for most HBCU alumni and an individual's relatedness, specifically their sense of belonging, within a graduate pathway, discipline, and/or institution, yet this cluster highlights the small minority where those areas did not appear to play a significant role. Because this finding drifts away from most literature related to the importance and critical role these groups play in HBCUs students' success with undergraduate and graduate degrees, a detailed look at the demographic data help further explain this finding. This group comprises the second highest percentage of alumni who were first-generation college students across all the clusters (41.2%). Moreover, 79.4% of the cluster's highest degree of completion were Master's degrees. It is then possible that a high percentage of these respondents are/could have been either enrolled as part-time graduate students or in shorter course-based Master's programs, which may have impacted their feelings of relatedness to their peers and the graduate program. Lastly, across all the clusters, most of the alumni pursued a graduate degree at a PWI. However, this cluster includes 23.5% who pursued a graduate degree at HBCUs.

6.3.3 Cluster 3: Deliberation around Attending Graduate School (n = 13)

The HBCU alumni represented within this cluster were more conflicted than any other cluster with their decision whether to pursue a graduate degree (M = 2.25, SD = 0.83). This tension in decision-making may have been influenced by the high percentage of first-generation college graduates (46.2%). However, this challenge did not appear to negatively impact their preparation (M = 6.15, SD = 0.98) or their success once in graduate school, as measured by their high level of confidence during their graduate experience, which was the highest of any cluster (M = 6.72, SD = 0.47).

These alumni also indicated strong familial influence (M = 5.18, SD = 1.08) and they prioritized institutions where they were likely to be accepted and where they would be provided financially supportive options (either due to affordability or the availability of financial support; M = 6.23, SD = 0.88). In addition, these HBCU alumni were more likely to have been encouraged to attend an HBCU for graduate school and/or to seek out reputable programs (M = 5.35, SD = 0.77). These two points connect back to the potential for a supportive institutional climate (by being encouraged to stay at an HBCU or seek a program with available financial support). While 7% did pursue graduate degrees at an HBCU, approximately 85% pursued their degree at a PWI. In general, the alumni within this cluster completed Master's degrees (85%) and almost half were outside of STEM fields (46.2%). Still, given how their researcher identity development was strongly supported both within their undergraduate and graduate experiences (M = 6.23, SD = 0.92), this factor could also have played a critical role in their feelings of relatedness and competency, contributing to their success within graduate school.

These findings align with literature that emphasizes the critical role an institution's culture and climate has in supporting students' personal identities, which is a key element of promoting the success, persistence, and retention of minority students within STEM disciplines (Collins, 2018). Recent studies also highlight the relationship between race and gender in STEM identity development, demonstrating the importance and effectiveness in understanding identity in shaping Black student experiences, particularly regarding student engagement as well as barriers to success within STEM majors (Berhane et al., 2020; McKoy et al., 2020). Essentially, HBCUs, regardless of the student's identity traits (in this case, first-generation), provide a culture that embraces students' differences and prepares them for successful pathways postgraduation. These findings are consistent with literature noting the sustainable models of inclusive STEM environments offered by HBCUs (Flowers, 2013; Toldson, 2018, 2019).

6.3.4 Cluster 4: High Commitment, Success, and Support (n = 47)

The fourth cluster comprises HBCU alumni who held the strongest commitment to pursuing a graduate degree across the clusters (M = 6.16, SD = 0.81) and had the most satisfaction with their graduate school experience (M = 6.07, SD = 0.86). This high level of satisfaction could be attributed to their high level of preparation for graduate school (M = 6.38, SD = 0.51) or their well-developed researcher identity (M = 5.99, SD = 0.85), both which contribute to high levels of perceived competence and to one's sense of belonging within the research community. In their decision-making process, this group was influenced to some extent by their family (M = 4.28, SD = 1.24) and by a common expectation from peers and the disciplinary culture to attend graduate school (M = 5.97, SD = 0.96). These influences also played a role in which graduate programs the alumni applied to, specifically graduate programs that provided financial support or were affordable as well as those programs where the alum had a higher likelihood of receiving admission (M = 6.06, SD = 0.84).

Of important note within this cluster is that is contains the highest percentage of alumni who attended an HBCU for graduate school (44.7%). This statistic, along with the high level of satisfaction with the graduate school experience, could be examined in a few ways. First, more students of all backgrounds are choosing to attend HBCUs because of their inclusive culture and the ongoing increasing racial tensions within the U.S. (Williams and Toldson, 2020). Second, this finding is compounded with the fact that most of the participants in this cluster identified as women (68.1%). From an enrollment and degree completion standpoint, this statistic is a significant contribution to the literature given the fact that, on average, 55% of STEM degrees awarded at the undergraduate level within the Black population are to men and 45% to women. For engineering specifically, the statistic is 76% men and 24% women (Fletcher et al., 2021). Indicating that while the number of Black women that obtain undergraduate degrees is lower, they are attending graduate school, enjoying their experiences, believed their preparation for graduate school was done well by their HBCUs, and that their overall satisfaction is high. This connection aligns well with literature highlighting the purpose behind attending HBCUs, commitment to their education, and high levels of satisfaction and the influencing factors for Black women to attend HBCUs (Johnson et al., 2020; Perna et al., 2009; Washington Lockett et al., 2018).

Additionally, over 40% of the alumni in this cluster indicated that one or both of their parents received a Master's degree. This finding aligns with literature that students, in general, whose parents attended graduate school are also more likely to pursue a graduate degree (Mullen et al., 2003). The high percentage of alumni with parents who had graduate school experience may have contributed to how family influenced alumni. In terms of the graduate experience, 41.4% of this group pursued a non-STEM graduate degree and almost 74.5% of those who have already completed a degree received a Master's degree.

6.3.5 Cluster 5: High Personal Agency and Support in Engineering (n = 10)

This cluster included HBCU alumni with the second highest level of commitment to pursue a graduate degree among the clusters (M = 5.70, SD = 1.09). These alumni also reported high levels of success and support within their HBCU experience. Two such supports were faculty mentors as well as research experiences (M = 6.00, SD = 0.75). The role of previous research experiences may have contributed to the higher levels of researcher identity development (M = 6.07, SD = 0.78) and feelings of relatedness to the research community and competency as a researcher. Additionally, this cluster includes the highest percentage of individuals who pursued engineering degrees during their HBCU undergraduate experience (70%).

In contrast to other clusters, family played a smaller role for these HBCU alumni as they made their decision to pursue graduate school and where to apply (M = 2.53, SD = 0.67). Still, 70% of the parents of the alumni in this cluster earned graduate degrees, which may have influenced the alumni's understanding of graduate school and the application process. Also, it was less likely that these alumni were encouraged to attend

an HBCU for graduate school (M = 3.75, SD = 0.68). Ultimately, 90% of this cluster attended a PWI for graduate school and 60% of the graduate institutions attended were private institutions. Engineering and computer science were the most pursued graduate degree (the highest among the clusters in both disciplines) with 60% pursuing engineering degrees and 20% pursuing degrees in computer science. Of those that have already earned degrees, 60% received a doctoral degree. Upon graduation, 60% of these alumni are working in higher education institutions. Even with these high percentages of doctoral degrees and the current career pathways, note that this cluster comprised only individuals under 45. These findings provide a sort of *pathway map* for Black engineering students from HBCUs, the graduate programs they select and how academia, for those with doctoral degrees, is typically their landing location (Upton and Tanenbaum, 2014).

Overall, the most important overarching findings were that this cluster (1) had the second highest level of commitment to pursue a graduate degree among the clusters, (2) reported high levels of success and support within their HBCU experience (including faculty mentors and research experiences), and (3) had the highest percentage of individuals who pursued engineering degrees during their HBCU undergraduate experience (70%). Part of that success and support may have come from previous research experiences, given the higher levels of researcher identity development that were found. These findings support the expansive literature highlighting the importance of undergraduate research experiences along with its impact on increasing the interest and successful completion of graduate degrees for Black students (May and Chubin, 2003; Flowers, 2021; Umerah et al., 2021; Smith et al., 2021; Caine et al., 2018). Additionally, these connections support literature regarding how engineering at HBCUs has been successful with preparing future Black engineers (Fletcher et al., 2021).

7. OVERARCHING DISCUSSION AND CONCLUSIONS

Historically Black Colleges and Universities (HBCUs) have played a critical role addressing the underrepresentation of Black students within STEM fields and are needed to address the ongoing gaps in broadening participation that exist. Through this study, we sought to answer two research questions: (1) *How have undergraduate HBCU experiences contributed to the graduate pathways of Black HBCU alumni that majored in STEM and who pursued (or completed) graduate degrees?* And (2) *What differences are there among HBCU alumni regarding the individual, institutional, and cultural factors that contributed to their experiences within their graduate pathway?* The overall results presented herein highlight the impact of the undergraduate experiences on HBCU alumni and how that connected to their graduate school pathway and successful graduate degree completion. As shared within the Results and Discussion section, across all clusters, two (2) critical insights emerged that help us to address the first research question: (1) the HBCU experience empowered alumni, and (2) the perceptions of mentorship and support provided during an HBCU undergraduate experience were highly positive across all five clusters. These insights reinforce and provide detailed context on previous research highlighted within the literature review on HBCUs success in contributing to pathways

into and through STEM education and contributing towards the Black student enrollment and completion of STEM graduate degrees. Additionally, the positive institutional climate and positive perceptions of campus culture for HBCU students under their undergraduate degree programs have contributed to students' graduate school interest and paths taken to pursue and successfully complete graduate degrees.

While HBCUs, collectively, provided a space for students to focus academically and engage socially, findings from this study highlighted the individual differences that may have been influenced by a student's competence within research and their discipline as well as a student's relatedness to their peers, their research community, and their institution. Alumni's perceptions of their competency may have impacted their researcher identity and overall satisfaction with graduate school. Within cluster 3, *deliberation around attending graduate school*, perceived competency was high within the alumni's graduate experience. The topic of relatedness connected to both (1) parental background in graduate programs (observed in clusters 1, *pathway challenges into, during, and out of graduate school, and 5, high personal agency and support in engineering*) and (2) the mentorship and support provided during the HBCU experience (observed across all clusters, and a critical component of cluster 5). Overall, institutional climate was found to be an important factor for Black HBCU students as they planned their postgraduate pathway. For example, within cluster 1, non-traditional students were more than likely to choose an institution that had resources that would support areas of their life including childcare, financial support, and other services that would help address miscellaneous time constraints. Additionally, high levels of intrinsic motivation were observed in cluster 5, as these participants showcased the connection between motivation and achievement when students have support from their institution.

Ultimately, these findings reinforce HBCUs' ability to provide a culture and climate that is supportive of its students and their pathways into graduate school. One of the most important contributions to the literature is around students' experiences within PWI graduate programs that did not have as positive outcomes compared to the high level of satisfaction by alumni who experienced a supportive environment within graduate school at an HBCU. This notable difference in satisfaction across the clusters, especially given existing literature, cannot be undermined, or ignored. HBCUs excel at supporting identity development through the institution encouraging student-centric approaches that honor Black students with culturally competent practices, relevant teachings, and professional training (Toldson, 2018; Smith et al., 2021; Williams et al., 2021; Aycock et al., 2022). There is still much to be explored in how HBCUs model responsive institutional climate. Overall, though, the results illustrate how HBCUs afford understanding for the Black student experience and non-traditional backgrounds by leveraging culturally competent practices, by which students firmly establish their individual identity (Strayhorn, 2008). This finding around competence directly connects to one of three focus areas tied to the theoretical foundation of this work, self-determination theory, with competence. Additionally, with racial identity largely celebrated, Black students have the space to explore other parts of their identity, ultimately nourishing their self-efficacy and supporting their further classroom experience and professional identity develop-

ment. This finding connects back to another focus area of self-determination theory, relatedness, further acknowledging the importance of students' being able to have a sense of belongingness as they pursue degrees they have historically been excluded from.

8. IMPLICATIONS AND LIMITATIONS

Based on the study results, recommendations include increased emphasis on research across HBCUs and other minority-serving institutions (MSIs) as results highlight those students, even within the same ethnic group at the same institution designation, are not a monolith. For example, student experiences at HBCUs differ depending on varying identifiers including institution type (private or public), institution size, institution location, to name a few. An additional recommendation is for leaders within graduate programs at PWIs and any institution that has not had success with recruiting, retaining, and/or graduating HBCU alumni. Increasing intentionality around understanding HBCU alumni experiences to make improvements in areas where needed could help with overall broadening participation efforts. This could also increase the likelihood of HBCU alumni who attend those institutions to encourage the next generation or class of students to consider those institutions.

The first recommendation discussed connects to a limitation of this study. To clarify, while the findings provide an in-depth view of the student experience using factors such as age, major, and parental education status, other factors including the institution-based examples above, were not included or analyzed, as a part of the cluster analysis. This is particularly true for the private versus public HBCU designation. Several studies have highlighted these distinct differences, their historical underpinnings, their founding purposes, vision, and access to resources that can influence overall stakeholder (i.e., administration, faculty) and student success (Harper, 2010; Harper et al., 2009). Therefore, future research should examine the institutions in more detail, possibly through multisite case studies or other methods, to specifically articulate the differences among institutions and the impact of their histories on the current climate and culture for students pursuing graduate degrees.

Additionally, our team would like to recognize that these data were collected during the early onset of COVID-19. While we cannot determine if that would have affected the quality and substance of responses, we acknowledge this note. Generally, COVID-19 challenged the traditional in-person learning across all higher education institutions. However, COVID-19 pandemic cause disproportionate negative impacts on students and faculty at institutions serving large populations of minorities (Toldson et al., 2020). For example, previous research highlights resource disparities that were exacerbated following COVID-19, including how PWIs and more financially affluent institutions had more resources to support diversity within instructional learning (Thompson and Rodriguez-Nikl, 2021) as well as access to educational technologies necessary for the abrupt transition into remote instruction (Mitchell, 2021). Equipping students and faculty of color with equitable teaching and learning resources is the foundation in addressing the complex, multilayered challenges that underserved students were previewed to during COVID-19. Additionally, and because of the inadequate resources to protect Black communities during a pandemic, Black students

carry the heavy burden of emotional and mental health traumas as they transition back to campus (Landertinger et al., 2021). Thus, not only do HBCUs need equitable funding for hybrid instruction, but additional resources to support the emotional and mental well-being of Black students are also essential for their learning experiences (Fletcher et al., 2022).

Implications for practice include capitalizing on the areas of success such as impact of faculty mentorship and research opportunities. For example, there are institutions (i.e., Rochester Institute of Technology) that require cooperative education programs as a part of their academic program curriculum. If there are research-proven aspects of a student's (or alumni, in this case), experience that contributed towards their success in graduate school, this may be an area to consider making a required part of the program curriculum. Therefore, HBCUs could consider making faculty mentorship programs and/or year-round or summer research position or internships a required component of the academic curriculum. Additionally, there should be an increased focus on investments in areas such as financial support (i.e., scholarships, grants, fellowships) and resources that help students manage obligations that threaten to prevent them from focusing on their academics. Lastly, further research is required to understand the potential variation in academic trajectories for students from community colleges, whose interests in engineering and computing careers may emerge later in their undergraduate journey. This focus has been particularly noted for non-STEM majors who gain later experience with introductory computing courses before deciding to transition to computing (Lehman et al., 2020).

Based on all aspects of this study, the future direction of our work will consist of analyzing other aspects of the survey data that were collected including a deeper dive into limitation areas shared here as well as analysis of qualitative data collected within the survey. As a part of a funded grant from the National Science Foundation, qualitative data in the form of individuals and focus group interviews will be conducted with HBCU stakeholders including current students, recent alumni, faculty, staff, and administrators (Jefferson et al., 2021). Findings from this study will help drive the interview protocol and other aspects of the data collection process within our larger study (Jefferson et al., 2021).

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APPENDIX.

TABLE A1: Summary details of survey

Block	Number of items	Description	Cronbach's α
Undergraduate experience	15	The items in this block were designed to capture the dimensions of institutional climate experienced by HBCU alumni at their undergraduate institution.	0.83
Graduate school applications and decisions	18	The items in this block were developed to focus on respondent perceptions of their graduate school pathways (from preparation for and completion of graduate school).	0.69
Graduate experience	12	The items in this block were designed to evaluate the dimensions of institutional climate and their individual success during our respondents' graduate school experiences.	0.83

TABLE A2: Student participation and representation for stakeholder survey and overall study

	***N* (= 151)**	**%**
Gender identity		
Female	98	64.9
Male	52	34.4

TABLE A2: (*continued*)

Non-Binary	1	0.7
Other		
Race/Ethnicity		
African American or Black	146	96.7
American Indian or Alaskan Native		
Multiracial (2 or more)	4	2.65
Other	1	0.7
Age		
18–25	24	15.9
26–35	55	36.4
36–45	41	27.2
45–55	23	15.2
56–65	7	4.6
66 or Older	1	0.7
Discipline of undergraduate degree		
Engineering	61	40.4
Computer science	11	7.3
Non-engineering STEM	63	41.7
Non-STEM	16	10.6
Undergraduate first-generation status		
Yes	50	33.1
No	100	66.2
Not sure	1	0.7
Parents' highest level of education		
Associate's degree	14	9.3
Bachelor's degree	36	23.8
Did not complete high school	5	3.3
Doctorate's degree	10	6.6
High school diploma/GED	34	22.5
Master's degree	50	33.1
Prefer not to disclose	2	1.3
Undergraduate international student status		
Yes	8	5.3
No	143	94.7
Graduate institution type (1)		
HBCU	37	24.5

TABLE A2: (*continued*)

	***N* (= 151)**	**%**
Non-HBCU MSI	3	2.0
PWI	108	71.5
Not sure	3	2.0
Graduate institution type (2)		
Public	96	63.6
Private	48	31.8
Not sure	7	4.6
Graduate degree completed		
Master's	101	66.9
PhD	55	36.4
JD	1	0.7
EdD	1	0.7
Doctorate (other)	5	3.3
Other	20	13.2
Current position in career		
In graduate school	36	23.8
Prefer not to disclose	2	1.3
Unemployed	1	0.7
Working in academia	47	31.1
Working in an U.S. Government Department or Agency	18	11.9
Working in industry	47	31.1

TABLE A3(a): *Undergraduate experience block*

Items	**Loadings**	**VIF**
Faculty mentorship		
I developed connections with influential members (i.e., faculty, administration, or staff) of my undergraduate HBCU	0.79	1.32
Faculty at my undergraduate institution served as my role models for how to achieve academic success	0.69	1.66
Overall, I was empowered by my professors' commitment to my academic success	0.66	1.86
I had a STEM faculty member whom I considered as my mentor	0.70	1.46
HBCU support system and student success		
My interactions with academic support staff (i.e., advisors) had a positive influence on my academic success as an undergraduate student	0.52	1.79

TABLE A3(a): (*continued*)

I was well informed about the academic support services (e.g., tutoring, writing assistance, etc.) that were available to me at my undergraduate institution	0.62	1.46
I received support regarding my overall professional development (e.g., resume writing, interview preparation, career fairs, etc.)	0.70	1.77
I regularly interacted with STEM students who planned to apply to and attend graduate school	0.64	1.50
I regularly interacted with STEM students from different demographic groups (e.g., different races, genders, ages, etc.)	0.66	1.42
I received helpful information about STEM-related opportunities (e.g., research, academic, professional, etc.) from my student peers	0.72	1.91
HBCU student empowerment		
Attending an HBCU helped give me the confidence to pursue a graduate degree	0.65	1.32
The values and principles of my undergraduate HBCU encouraged me to achieve academic success	0.59	1.83
I received sufficient financial assistance (i.e., Pell grant or scholarship) during my time as an undergraduate	0.63	1.33

Removed items are "My undergraduate institution properly addressed discriminatory words, behaviors, symbols, attitudes, or gestures directed at students." and "Overall, faculty members encouraged me to make connections with my classmates."

TABLE A3(b): Graduate school applications and decisions block

Items	**Loadings**	**VIF**
Faculty and research influences on decision-making		
My professors encouraged me to apply to graduate school	0.69	1.68
My decision to apply to graduate school was positively influenced by the research opportunities I participated in	0.78	1.48
I prioritized applying to graduate programs that best fit my research interests	0.61	1.45
The graduate programs I decided to apply to were influenced by my faculty mentors and/or professors	0.58	1.47
Family influence on decision-making		
My family encouraged me to apply to graduate school	0.63	1.44
I prioritized applying to graduate programs that were near home	0.61	1.75
My family's preferences for specific graduate programs influenced the applications I chose to submit	0.81	1.72
Peer influences on decision-making		
Attending graduate school was a common expectation of students in my undergraduate major	0.69	1.42

TABLE A3(b): (*continued*)

Items	Loadings	VIF
I was confident I would be successfully accepted to a graduate school program	0.62	1.41
Conflicting commitment and choice		
I struggled between deciding to apply for graduate school or applying for work (or continuing work) after graduation	0.74	1.60
I was worried applying to a graduate program would conflict with my commitments to my family	0.81	1.51
Prioritizing access		
I prioritized applying to graduate programs that I was confident I would get accepted into	0.72	1.71
I prioritized applying to graduate programs that were affordable and/or provided financial support	0.82	1.48
Program reputation and choice		
I prioritized applying to graduate programs that were reputable	0.68	1.79
I was encouraged to attend an HBCU for graduate school	–0.68	1.42

Removed items are "My student peers encouraged me to apply to graduate school" and "My decision to apply to graduate school was positively influenced by my experiences with STEM-related organizations."

TABLE A3(c): Graduate experience block

Items	Loadings	VIF
HBCU undergraduate preparation for graduate success		
STEM-related courses from my undergraduate degree prepared me for my graduate school coursework	0.71	1.78
The academic support I received at my undergraduate institution (has) helped me transition into my first semester (or quarter) of graduate school	0.78	2.13
Overall, my undergraduate institution prepared me for academic success as a graduate student	0.84	2.65
Graduate student confidence		
I was confident in my success as a graduate student upon completion of my first year in my graduate program	0.65	2.41
I was confident I could meet the expectations of my graduate advisor when I started the graduate program	0.81	2.56
I am/was confident in communicating my ideas with my graduate research advisor	0.70	1.78
Graduate researcher identity development		
The STEM-related research opportunities outside of my courses prepared me for my graduate research	0.73	1.60

TABLE A3(c): (*continued*)

My research experiences at my undergraduate institution have helped me to develop a strong identity as a researcher during my time in graduate school	0.73	2.29
My research experiences at my graduate institution have helped me to develop a strong identity as a researcher during my time in graduate school	0.79	1.79
Graduate student satisfaction		
A lack of diversity within my graduate program had a negative impact on my mental health	0.70	1.31
I am confident I made the right choice in choosing the institution I attend/attended for graduate school	0.79	1.53
Overall, I am satisfied with my decision to attend graduate school	0.59	1.42

TABLE A4: Group comparison on each factor

	Group	***N***	***Mean rank***	***H***	***df***	***p***
Mentorship	Cluster 1	14	52.50	19.75	4	0.001
	Cluster 2	34	40.88			
	Cluster 3	13	73.12			
	Cluster 4	47	67.28			
	Cluster 5	10	78.35			
Support	Cluster 1	14	27.25	28.57	4	< 0.001
	Cluster 2	34	46.85			
	Cluster 3	13	82.69			
	Cluster 4	47	70.64			
	Cluster 5	10	65.15			
Empowerment	Cluster 1	14	55.00	6.26	4	0.181
	Cluster 2	34	50.78			
	Cluster 3	13	75.50			
	Cluster 4	47	62.99			
	Cluster 5	10	58.25			
Research	Cluster 1	14	54.61	22.05	4	< 0.001
	Cluster 2	34	37.84			
	Cluster 3	13	72.54			
	Cluster 4	47	70.91			
	Cluster 5	10	69.40			
Family	Cluster 1	14	44.64	30.67	4	< 0.001
	Cluster 2	34	51.07			

TABLE A4: (*continued*)

	Group	*N*	*Mean rank*	*H*	*df*	*p*
	Cluster 3	13	91.23			
	Cluster 4	47	68.86			
	Cluster 5	10	23.70			
Commitment	Cluster 1	14	39.14	71.36	4	< 0.001
	Cluster 2	34	84.57			
	Cluster 3	13	106.96			
	Cluster 4	47	36.72			
	Cluster 5	10	48.10			
Access	Cluster 1	14	42.86	40.20	4	< 0.001
	Cluster 2	34	52.28			
	Cluster 3	13	80.27			
	Cluster 4	47	74.43			
	Cluster 5	10	10.20			
Peer	Cluster 1	14	65.04	50.29	4	< 0.001
	Cluster 2	34	30.68			
	Cluster 3	13	89.08			
	Cluster 4	47	75.54			
	Cluster 5	10	35.90			
Reputation	Cluster 1	14	29.21	40.65	4	< 0.001
	Cluster 2	34	49.59			
	Cluster 3	13	82.23			
	Cluster 4	47	76.24			
	Cluster 5	10	27.35			
Preparation	Cluster 1	14	19.00	53.56	4	< 0.001
	Cluster 2	34	39.13			
	Cluster 3	13	73.77			
	Cluster 4	47	80.72			
	Cluster 5	10	67.15			
Confidence	Cluster 1	14	10.93	53.91	4	< 0.001
	Cluster 2	34	48.94			
	Cluster 3	13	94.73			
	Cluster 4	47	73.05			
	Cluster 5	10	53.90			
Identity	Cluster 1	14	34.57	47.24	4	< 0.001
	Cluster 2	34	33.28			

TABLE A4: (*continued*)

	Cluster 3	13	83.58			
	Cluster 4	47	75.44			
	Cluster 5	10	77.35			
Satisfaction	Cluster 1	14	33.36	19.76	4	0.001
	Cluster 2	34	52.50			
	Cluster 3	13	63.38			
	Cluster 4	47	73.95			
	Cluster 5	10	46.95			

Cluster 1: Pathway challenges into, during, and out of graduate school; Cluster 2: Variation in factors influencing graduate school choice; Cluster 3: Deliberation around attending graduate school; Cluster 4: High commitment, success, and support; Cluster 5: High personal agency and support in engineering.

TABLE A5: Group comparison on external items

	Group	***N***	***Mean rank***	***H***	***df***	***p***
Overall, faculty members encouraged me to make connections with my classmates	Cluster 1	14	39.50	27.104	4	< 0.001
	Cluster 2	34	43.00			
	Cluster 3	13	72.35			
	Cluster 4	47	73.78			
	Cluster 5	10	59.80			
My student peers encouraged me to apply to graduate school	Cluster 1	14	36.71	16.601	4	0.002
	Cluster 2	34	51.68			
	Cluster 3	13	77.12			
	Cluster 4	47	68.68			
	Cluster 5	10	51.95			
My decision to apply to graduate school was positively influenced by my experiences with STEM-related organizations	Cluster 1	14	60.36	29.542	4	< 0.001
	Cluster 2	34	35.94			
	Cluster 3	13	80.88			
	Cluster 4	47	69.95			
	Cluster 5	10	61.50			

Cluster 1: Pathway challenges into, during, and out of graduate school; Cluster 2: Variation in factors influencing graduate school choice; Cluster 3: Deliberation around attending graduate school; Cluster 4: High commitment, success, and support; Cluster 5: High personal agency and support in engineering.

TABLE A6: Student participation and representation for stakeholder survey and overall study

	Cluster 1 (*N* = 14)		**Cluster 2 (*N* = 34)**		**Cluster 3 (*N* = 13)**		**Cluster 4 (*N* = 47)**		**Cluster 5 (*N* = 10)**	
Factor characteristics	M	SD	M	SD	M	SD	M	SD	M	SD

TABLE A6: (*continued*)

	Cluster 1 (*N* = 14)		Cluster 2 (*N* = 34)		Cluster 3 (*N* = 13)		Cluster 4 (*N* = 47)		Cluster 5 (*N* = 10)	
Mentorship	6.38	0.76	6.20	0.64	6.75	0.41	6.68	0.45	6.88	0.18
Support	5.27	0.88	5.83	0.81	6.55	0.44	6.36	0.46	6.23	0.55
Empowerment	6.45	0.56	6.31	0.68	6.69	0.55	6.50	0.67	6.43	0.65
Research	5.59	0.94	5.01	1.07	6.08	0.78	6.03	0.81	6.00	0.75
Family	3.38	0.81	3.55	1.34	5.18	1.08	4.28	1.24	2.53	0.67
Commitment	6.07	0.85	3.91	1.22	2.35	0.83	6.16	0.81	5.70	1.09
Access	4.82	1.31	5.24	1.23	6.23	0.88	6.07	0.84	2.70	1.18
Peer	5.68	0.58	4.57	0.79	6.38	0.77	5.97	0.96	4.60	1.17
Reputation	3.82	0.67	4.37	0.81	5.35	0.83	5.22	0.99	3.75	0.68
Preparation	4.33	1.10	5.37	0.76	6.15	0.98	6.38	0.51	6.10	0.61
Confidence	3.17	1.10	5.41	0.95	6.72	0.47	6.13	0.84	5.60	0.98
Identity	4.69	0.81	4.57	1.01	6.23	0.92	5.99	0.85	6.07	0.78
Satisfaction	4.71	1.31	5.55	0.85	5.87	0.74	6.07	0.86	5.40	0.89

Cluster 1: Pathway challenges into, during, and out of graduate school; Cluster 2: Variation in factors influencing graduate school choice; Cluster 3: Deliberation around attending graduate school; Cluster 4: High commitment, success, and support; Cluster 5: High personal agency and support in engineering.

TABLE A7: Description of clusters

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Cluster characteristics	(*N* = 14)	(*N* = 34)	(*N* = 13)	(*N* = 47)	(*N* = 10)
Discipline of undergraduate degree					
Computer science	0.0%	14.7%	7.7%	4.3%	0.0%
Engineering	28.6%	38.2%	30.8%	53.2%	70.0%
STEM: Non-engineering	64.3%	29.4%	46.2%	36.2%	30.0%
Non-STEM/other	7.1%	17.6%	15.4%	6.4%	0.0%
Degree completed					
JD	7.1%	0.0%	0.0%	0.0%	0.0%
MS	35.7%	70.6%	53.8%	76.6%	60.6%
PhD	57.1%	23.5%	15.4%	42.63%	70.0%
Doctorate (other)	0.0%	0.0%	15.4%	6.4%	0.0%
Other	7.1%	20.6%	23.1%	2.1%	10.0%
Discipline of graduate degree					
Computer science	0.0%	11.8%	7.7%	2.1%	20.0%
Engineering	50.0%	44.1%	23.1%	55.3%	60.0%
STEM: Non-engineering	20.7%	20.7%	10.3%	41.4%	6.9%

TABLE A7: (*continued*)

Non-STEM/other	7.1%	26.5%	46.2%	17.0%	0.0%
Graduate institution type					
HBCU	7.1%	23.5%	7.7%	44.7%	10.0%
PWI	92.9%	67.6%	84.6%	51.1%	90.0%
Non-HBCU MSI	0.0%	2.9%	0.0%	4.3%	0.0%
I am not sure	0.0%	5.9%	7.7%	0.0%	0.0%
Graduate institution sector					
Public	78.6%	55.9%	46.2%	66.0%	40.0%
Private	21.4%	35.3%	38.5%	31.9%	60.0%
I am not sure	0.0%	8.8%	15.4%	2.1%	0.0%
Undergraduate first-generation status					
Yes	21.4%	41.2%	46.2%	25.5%	30.0%
No	78.6%	55.9%	53.8%	74.5%	70.0%
I am not sure	0.0%	2.9%	0.0%	0.0%	0.0%
Parents' highest level of education					
Did not complete high school	7.1%	0.0%	0.0%	4.3%	0.0%
High school diploma/GED	21.4%	23.5%	38.5%	21.3%	20.0%
Associate degree	0.0%	11.8%	0.0%	6.4%	10.0%
Bachelor's degree	21.4%	29.4%	30.8%	19.1%	0.0%
Master's degree	35.7%	26.5%	23.1%	42.6%	50.0%
Doctorate's degree	14.3%	5.9%	0.0%	6.4%	20.0%
Prefer not to disclose	0.0%	2.9%	7.7%	0.0%	0.0%
Gender					
Female	57.1%	61.8%	53.8%	68.1%	60.0%
Male	35.7%	38.2%	46.2%	31.9%	40.0%
Non-binary	7.1%	0.0%	0.0%	0.0%	0.0%
Spanish-speaking culture					
Yes	0.0%	8.8%	7.7%	2.1%	10.0%
No	100.0%	91.2%	92.3%	97.9%	90.0%
Undergraduate international student status					
No	100.0%	100.0%	100.0%	89.4%	100.0%
Yes	0.0%	0.0%	0.0%	10.6%	0.0%
Age					
18–25	7.1%	23.5%	15.4%	8.5%	0.0%
26–35	57.1%	32.4%	30.8%	36.2%	50.0%
36–45	0.0%	17.6%	38.5%	34.0%	50.0%

TABLE A7: (*continued*)

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
46–55	35.7%	11.8%	7.7%	17.0%	0.0%
56–65	0.0%	11.8%	7.7%	4.3%	0.0%
66 or older	0.0%	2.9%	0.0%	0.0%	0.0%
Current career					
In graduate school	14.3%	35.3%	15.4%	14.9%	30.0%
Working in academia	35.7%	20.6%	23.1%	36.2%	60.0%
Working in a U.S. Government Department or Agency	35.7%	8.8%	15.4%	10.6%	10.0%
Working in industry	14.3%	32.4%	38.5%	36.2%	0.0%
Unemployed	0.0%	0.0%	0.0%	2.1%	0.0%
Prefer not to disclose	0.0%	2.9%	7.7%	0.0%	0.0%

Cluster 1: Pathway challenges into, during, and out of graduate school; Cluster 2: Variation in factors influencing graduate school choice; Cluster 3: Deliberation around attending graduate school; Cluster 4: High commitment, success, and support; Cluster 5: High personal agency and support in engineering.