Mapping the Leaky Pipeline: Visualizing Black Female Persistence in Electrical Engineering

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Abstract
This paper builds upon my prior research that examined the lived experiences of Black female students in undergraduate electrical engineering (EE) programs at Minority Serving Institutions (MSIs), where I identified three core conclusions: (1) identity formation is deeply shaped by early exposure and representation, (2) resilience is often developed in response to structural barriers rather than supported by institutional design, and (3) belongingness and mentoring remain critical yet inconsistently available supports. That earlier work, grounded in intersectionality and STEM identity theory, used student narratives and thematic analysis to illuminate how multiply marginalized students navigate engineering spaces. In the present study, we extend that inquiry by shifting from qualitative narrative to quantitative visualization, constructing a data-driven pipeline model that traces the educational trajectory of Black female students from K–12 STEM exposure through EE degree attainment. To translate qualitative themes into measurable indicators, we aligned constructs such as early exposure, identity development, and persistence with publicly available national datasets and organizational reports. This mapping enabled the identification of key drop-off points along the EE pathway, including disparities in early STEM access, intent-to-major gaps, enrollment bottlenecks, and persistence challenges within engineering curricula. The resulting Broadening Participation Pipeline Tracker, a visualization tool we developed for this study, uses a Sankey diagram to model student flow across the educational continuum, quantify attrition, and highlight where targeted interventions may yield the greatest impact. While Black women in EE serve as the focal application of the model, the framework itself is generalizable and can be adapted to other marginalized groups and STEM disciplines. By integrating national datasets with insights from prior qualitative research, this work bridges the gap between narrative and numeric, offering a holistic view of the structural dynamics that shape engineering education. Ultimately, it contributes both a methodological innovation and a strategic tool for equity-centered research, grant development, curriculum design, and policy-informed intervention planning.

Keywords
Black women in engineering education, intersectionality in STEM, engineering education pipeline analysis, broadening participation, quantitative visualization of student trajectories, equity-centered intervention design

Background
Efforts to reform engineering education in the United States have long emphasized increasing technical rigor, expanding access, and diversifying participation. Landmark initiatives such as the ABET accreditation reforms of the 1990s and the National Science Foundation's ADVANCE program sought to address systemic inequities in STEM; however, persistent disparities remain, particularly for Black women in fields like electrical engineering (EE) [1], [2]. Despite overall growth in engineering enrollment, the representation of Black women has remained virtually unchanged, with less than 1% of engineering bachelor's degrees awarded to this group over the past decade [3-4]. Minority Serving Institutions (MSIs), including Historically Black Colleges and Universities (HBCUs), Hispanic-Serving Institutions (HSIs), and Tribal Colleges and

Universities (TCUs), play a critical role in countering these trends. HBCUs, in particular, produce a disproportionate share of Black STEM graduates relative to their enrollment size and offer culturally affirming environments that support persistence and identity development [5-6]. These institutions frequently embed mentorship, community engagement, and culturally responsive pedagogy into their engineering programs, creating counter spaces that buffer against the isolation, stereotype threat, and racialized gender bias commonly reported at Predominantly White Institutions (PWIs) [7].

In contrast, Black women in engineering at PWIs often encounter racially gendered hypervisibility, limited access to identity-matched mentorship, and institutional climates that inadequately support their academic and social inclusion [8]. Research shows that these students frequently experience a dual burden: being highly visible as representatives of their race and gender, yet simultaneously rendered invisible in classroom discourse, faculty engagement, and peer networks [8-9]. These dynamics contribute to lower retention and graduation rates, even among students who enter engineering programs with strong preparation and intent. The longstanding "leaky pipeline" metaphor, used to describe attrition across STEM pathways, requires reinterpretation through an intersectional lens that accounts for institutional context, structural barriers, and identity-based exclusion. Comparing trajectories across MSIs and PWIs, this study builds on a growing body of equity-centered research in engineering education. It positions the Broadening Participation Pipeline Tracker within this historical and institutional landscape, offering a data-driven tool to visualize disparities, identify intervention points, and support systemic change in the recruitment, retention, and advancement of Black women in electrical engineering.

Introduction

To visually connect this study to our prior qualitative work, we first recreated the thematic structure presented as Table 2 in the original study [10]. In that earlier paper, the themes and sub-codes were presented only in tabular form and did not include a visual model illustrating how these factors interact to shape the experiences of Black women in electrical engineering. In the present paper, this recreated table appears as Table 1, providing a clear summary of the five major themes and their associated sub-codes before introducing the new conceptual diagram. These themes, contributions to choosing engineering, difficulty of preparation, support systems, expectations and aspirations, and accessibility to mentoring, form the qualitative foundation upon which the current quantitative pipeline analysis is built.

Table 1: Identified themes depicting the impact of factors on the participation and persistence of Black women in EE [10]

Theme	Definition	Sub-codes
Contributions to the choice of engineering	Factors that influenced choice and contributed to increased interest in engineering	Family or relatives, STEM awareness or engagement, curiosity or interest, strength in engineering, teacher or mentor, motivation, engineering capability, early exposure, engineering society or opportunity, internship

Theme	Definition	Sub-codes
Difficulty of preparation for engineering	Factors contributing to academic difficulty	Lack of opportunities, classroom and extracurricular learning, technology, family responsibilities, pandemic, difficult faculty, lack of motivation or planning, tutor or mentor, isolation
Support in the education pathway	People, events, or programs that enabled students to overcome challenges	Campus opportunities, family or relatives, professors or faculty, peers, personal development, early exposure
Expectations and aspirations	Aspirations during or after study	Community development or service, job in the industry, graduate studies
Accessibility to mentors	Utilization of mentoring services and the role mentors played in persistence	Uninhibited mentor–mentee relationship, lack of mentoring opportunities, mentoring services not utilized

In the conceptual diagram, figure 1, the five themes are represented in blue and their associated sub-codes in yellow, providing a visual translation of the thematic structure summarized in Table 1.

Fig. 1 Conceptual model adapted from prior qualitative themes.

Despite decades of national investment in STEM equity, Black women remain significantly underrepresented in engineering disciplines, particularly electrical engineering (EE). Prior research has illuminated the lived experiences of Black female students at Minority Serving Institutions (MSIs), revealing how identity development, resilience, and systemic barriers shape their trajectories through undergraduate engineering programs [10]. That work, grounded in intersectionality and STEM identity theory, emphasized the importance of belonging cues, mentorship, and institutional support in fostering persistence. However, while qualitative narratives offer rich insight into individual experiences, they often lack the structural visibility needed to inform policy and programmatic interventions at scale [11]. Building on this foundation, the present study introduces a sequential pipeline model that traces the educational trajectory of Black women in EE across five stages: (1) K–12 STEM exposure, (2) STEM/EE-aligned intent, (3) enrollment in EE, (4) persistence through the EE curriculum, and (5) graduation and early-career outcomes. Figure 2 provides a simplified block diagram of these stages, establishing the structural framework that underpins the subsequent Sankey visualization.

To ground the quantitative analysis in a clear structural framework, figure 2 depicts the sequential stages that define the pipeline model used in this study.

Fig. 2 Sequential stages of the Broadening Participation Pipeline Tracker, from early STEM exposure to graduation.

This paper extends the foundational qualitative work by constructing a data-driven visualization of the educational pipeline for Black female students in EE. Using publicly available national datasets and organizational reports, our analysis traces the flow of students from early STEM exposure through college enrollment, persistence, and graduation. The resulting Broadening Participation Pipeline Tracker employs a Sankey diagram to identify critical drop-off points and quantify disparities in representation. The leaky pipeline metaphor has long been used to describe attrition in STEM education, but its application to multiply marginalized populations, such as Black women in EE, requires a more nuanced lens. Nationally, Black women earn only 2.9% of STEM undergraduate degrees despite comprising 6.4% of all female undergraduates [12]. HBCUs play a pivotal role in mitigating this disparity, producing 46% of Black women who earned STEM degrees between 1995 and 2004 [13]. Yet even within these supportive environments, challenges persist, particularly in disciplines like electrical and computer engineering where gender parity remains elusive [14]. Integrating national statistics with structural mapping, this paper aims to make visible the systemic leaks that disproportionately affect Black women in engineering. It also offers a replicable framework for other disciplines and populations, supporting grant strategy, curriculum design, and outreach programming that center equity, identity development, and long-term persistence.

Methodology

The Broadening Participation Pipeline Tracker was developed to visualize the educational trajectory of Black women in electrical engineering (EE) using a sequential, stage-based model. This model captures both structural progression and attrition, enabling a dual analysis of persistence and systemic exclusion across the EE pathway. Data were sourced from national repositories and organizational reports, and each stage of the pipeline was represented as a node within a Sankey diagram, with flow widths proportional to the number of students progressing between stages. To operationalize the model, data were compiled from publicly available national datasets, organizational reports (including College Board reporting), and peer-reviewed studies. Because no single repository provides comprehensive race- and gender-disaggregated indicators across all stages of the STEM pathway, each pipeline stage drew from the most reliable public data available for that domain. The specific sources used for each metric are listed in tables 2–4, 6-7. K–12 indicators such as AP participation and performance were included because they offer standardized national measures that can be partially disaggregated by race and gender. The data were organized into four structured tables corresponding to each stage of the pipeline: Table 2 (K–12 STEM exposure), Table 3 (STEM/EE-aligned intent vs. enrollment), Table 4 (persistence through the EE curriculum), and Table 6 (graduation and post-graduate outcomes). Each table includes quantitative indicators, such as AP participation rates, enrollment percentages, and retention gaps, which informed the node sizes and flow widths in the Sankey diagram. When direct numerical values were unavailable for later stages of the pipeline, estimates were derived from longitudinal studies and institutional comparisons (e.g., MSI vs. PWI graduation rates) to maintain consistency across the model.

Pipeline Stage Data Tables

K-12 STEM Exposure

National datasets do not report STEM participation disaggregated by race × gender × subject, which prevents direct measurement of early STEM exposure for Black girls [15-16]. As a result, values in Table 2 rely on the most complete race-only and gender-only indicators available [15-16]. We explored whether a correction factor could be applied to adjust for the known underrepresentation of Black girls in STEM, but no consistent or citable estimate was identified. Only the AP STEM exam value required estimation; this estimate was derived by combining the race-only and gender-only distributions reported by the College Board, following NSF/NSB guidance that subgroup estimates may be derived when joint distributions are unavailable [17]. All other indicators in Table 2 are reported directly from their respective national sources.

Table 2: K-12 STEM Exposure

Metric	Value	Exposure
Black students in AP Physics [18]	2.4%	Early EE related physics
Black students in Calculus[18]	9.0%	EE relevant math foundation
% Black girls taking AP STEM exams (2022) [19]	~4.2%	Early EE aligned STEM coursework
Females in Calculus [18]	19.2%	EE relevant math preparation
Females in AP Physics [18]	3.7%	Early EE related physics

STEM/EE-Aligned Intent vs. Enrollment in EE

We used the *YouScience Black Students and STEM Report* to represent STEM/EE-aligned intent because no national dataset reports STEM college intention disaggregated by race, gender, and field. YouScience provides nationally representative, race-specific indicators of students' interest in STEM career clusters, which serve as validated predictors of STEM major selection and postsecondary pathway decisions. Students who express interest in a STEM career implicitly signal an intention to pursue the educational requirements associated with that field [20]. Although the dataset does not disaggregate interest by engineering discipline, it offers one of the most comprehensive national measures of STEM-related interest and aptitude among Black middle and high school students. Because no federal or national source reports race-specific or gender-specific intent to pursue electrical engineering at the high-school level, we used YouScience as a defensible proxy for early STEM/EE-aligned intent. The interest percentages presented in Table 3 reflect our calculations from the full sample of 328,000 Black students included in the report [21]. Although the YouScience intent data (2023) and National Center for

Education Statistics (NCES) Integrated Postsecondary Education Data System (IPEDS) enrollment data (2009), in Table 3, are not from the same year, they represent conceptually linked stages of the pipeline—expressed interest in high school and subsequent enrollment in college. Since no dataset reports both measures for the same cohort, these sources were paired to illustrate the structural gap between early STEM interest and electrical engineering enrollment.

Table 3: STEM/EE-Aligned /Intent vs. Enrollment in EE

Career Cluster	Students Showing Interest	Total Sample	% Indicating Interest (College-Intent)	Black Students EE Enrollment (2009)	% Black Women EE Enrollment (2009)
Computers & Technology	25,434	328,000	7.75%	42	28.57%
Advanced Manufacturing	27,586	328,000	8.41%	33	21.21%
Architecture & Construction	37,820	328,000	11.53%		

Persistence Through the EE Curriculum

Despite relatively strong interest in engineering-adjacent career clusters, the proportion of Black students who ultimately enroll in electrical engineering is substantially lower, revealing a pronounced leak between early intent and actual entry into the EE major. Although the percentage of Black women enrolled in electrical engineering appears numerically higher than the percentage indicating early STEM intent, the underlying population bases differ substantially. The YouScience dataset reflects a national sample of 328,000 Black middle and high school students, whereas the IPEDS enrollment values for Black engineering students—42 and 33 students, respectively—were obtained from the IPEDS Fall Enrollment survey for 2001 and 2009 [22]. When interpreted in context, the much smaller enrollment base confirms that actual participation in electrical engineering remains distinctly lower than early interest would suggest. This interpretation is further supported by institutional data from the four HBCUs in our previous study, which consistently showed low race × gender × engineering enrollment percentages, reinforcing that the small IPEDS enrollment counts reflect a broader national pattern of underrepresentation rather than a sampling anomaly. The substantial leak between early STEM intent and actual EE enrollment underscores the importance of examining what happens after students enter the major. Accordingly, Table 4 shifts the focus from initial access to the extent to which Black women persist through the electrical engineering curriculum. To contextualize mid-pipeline progression, Table 4 presents quantitative indicators of retention and attrition for Black women in EE. Enrollment patterns from our previous work further illustrate the gender imbalance shaping this stage: although NC A&T enrolled 166 EE students, only 18% were women; similarly, women represented 13.05% of EE students at MSU, 16.67% at TSU, and 14.9% at JSU [10]. These baseline disparities highlight the structural constraints Black women face even before persistence is measured, reinforcing the need to examine how many ultimately remain and complete the EE degree.

Table 4: Persistence Through the EE Curriculum (Black Students, 2020–2024)
Four-year progression from Fall 2020 enrollment to 2024 EE degree completion

Institution	2020 Black EE Enrollment (M/F)	2024 Total Black Graduate	2024 Black EE Graduates (M/F)	Black Women Persistence	Black Men Persistence
Jackson State University (JSU)	54 M / 10 F	13	11 M / 2 F	20%	20.4%
Morgan State University (MSU)	56 M / 8 F**	33	24 M / 9 F	N/A	N/A
Texas Southern University (TSU)	44 M / 10 F	5	5 M / 0 F	0%	11.4%
North Carolina A&T (NCA&T)	136 M / 30 F**	22	16 M / 6 F	N/A	N/A

**Race data for either gender not available

Interpretation of Table 4 requires acknowledging the uneven availability of race-specific and discipline-specific persistence data across institutions. For JSU and TSU, four-year persistence in electrical engineering could be calculated directly because both enrollment (2020) and degree completion (2024) were disaggregated by race x gender x EE. However, comparable Black-specific persistence rates could not be determined for MSU or North Carolina A&T because the 2020 enrollment data available for those institutions included only gender and discipline, without race-specific counts for electrical engineering. This limitation reflects a broader constraint within the IPEDS Fall Enrollment survey, which reports undergraduate enrollment at the engineering-discipline level but does not consistently disaggregate by race × gender × specific major for all institutions. To supplement these gaps, we incorporated 2024 degree-completion data from four PWIs—Johns Hopkins University, Mississippi State University, North Carolina State University, and the University of Houston—which provide race- and gender-specific counts of EE graduates. These data show that Black women's representation in EE completion remains extremely low across PWIs, with several institutions reporting zero Black women graduates in 2024, shown in Table 6. Taken together, the HBCU and PWI patterns reinforce the mid-pipeline leak observed nationally: even when Black students enter engineering programs, only a small fraction persist to earn an electrical engineering degree.

Figure 4 provides a visual summary of how Black students, disaggregated by gender, progressed through the electrical engineering curriculum between 2020 and 2024. The bar components highlight gender-specific persistence, while the line elements illustrate the relationship between initial enrollment and eventual degree completion. Together, these elements make the mid-pipeline leak visible in ways the table alone cannot.

Gender-Specific Persistence Patterns-Across the institutions shown, the persistence of Black women is consistently lower than that of Black men, with the exception of Texas Southern University, where no Black women completed the EE degree in 2024. Jackson State University shows the strongest gender balance, with both men and women persisting at relatively similar rates. In contrast, the gap widens at TSU, where men persist at a modest level while women drop to zero. Rather than pointing to a single cause, this pattern reflects the broader finding that Black women's non-completion in EE can stem from a range of factors, academic, structural, social, financial, or institutional, that operate differently across contexts. The figure does not identify which specific mechanisms were at play here, but it makes clear that multiple forces may contribute to why Black women are less likely to persist through the EE curriculum, even after successfully entering the major.

Enrollment-to-Graduation Drop-The figure's line elements—2020 enrollment and 2024 total Black graduates—make the magnitude of attrition immediately visible. At each institution, the 2024 graduation line sits far below the 2020 enrollment line, illustrating substantial losses of Black students over the four-year period. This drop is especially pronounced at institutions with larger initial cohorts, such as Jackson State and Texas Southern, where the number of graduates represents only a small fraction of the original enrollment. The visual gap between the two lines underscores the severity of the mid-pipeline leak: many Black students who begin in EE do not persist to degree completion, and the gender-specific bars show that Black women are disproportionately affected.

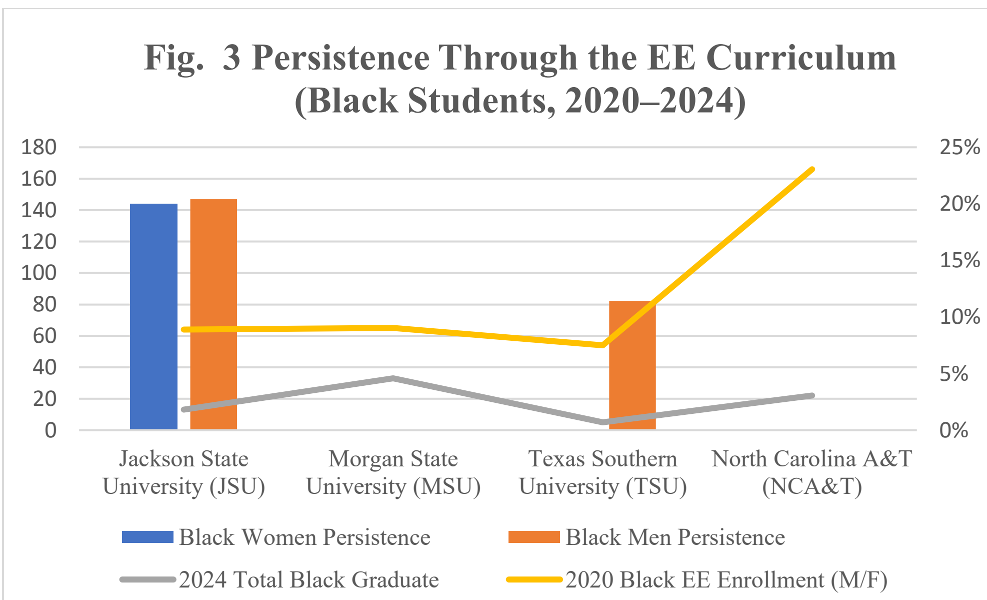

Fig. 3 Persistence Through the EE Curriculum (Black Students, 2020–2024)

HBCU PWI Comparison

Table 5 presents the PWIs located in geographic proximity to the HBCUs examined in our prior work, selected for their comparability in engineering program offerings. Including these institutions allows us to contextualize HBCU outcomes by demonstrating that Black women's underrepresentation in electrical engineering persists across both HBCUs and PWIs. For the subsequent analysis, one PWI was selected for each HBCU from this comparison list. The resulting HBCU–PWI degree-completion comparisons are presented in Table 6.

Table 5: HBCU PWI Comparison

HBCU	City	Best PWI Comparators (Engineering)
Morgan State (MSU)	Baltimore, MD	Johns Hopkins, UMBC, Towson
Texas Southern (TSU)	Houston, TX	University of Houston, Rice
Jackson State (JSU)	Jackson, MS	Mississippi State, Ole Miss
NC A&T	Greensboro, NC	NC State, UNC Charlotte

Shown in Table 6, across both HBCUs and PWIs, Black women's EE degree completion remains extremely low, with three institutions reporting zero Black women graduates in 2024 and none exceeding single-digit counts. This pattern underscores the severity of the leak at the end of the engineering pipeline: even after successfully entering EE programs, only a small number of Black women persist to degree completion at either HBCUs or PWIs. It is worth noting, however, that HBCUs graduated more Black women in electrical engineering than the selected PWIs in 2024, reflecting the broader trend in engineering education literature that HBCUs play a disproportionate role in producing Black STEM graduates [23-25].

Table 6: 2024 EE Degree Completion for Black Women (HBCU–PWI Comparison)
Black women earning EE degrees in 2024

Institution Type	Institution	Black Women EE Graduates (2024)
HBCU	Jackson State University (JSU)	2
HBCU	Morgan State University (MSU)	9
HBCU	Texas Southern University (TSU)	0
HBCU	North Carolina A&T (NCA&T)	6
PWI	Johns Hopkins University	0
PWI	Mississippi State University	1
PWI	North Carolina State University	1
PWI	University of Houston	0

The graphical representation of Table 6, in figure 4, makes the distribution of degree completion even more apparent by visually emphasizing the concentration of Black women EE graduates at HBCUs. Morgan State University and North Carolina A&T stand out immediately, with noticeably higher bars than any of the PWIs in the comparison group. In contrast, the PWIs cluster tightly at the bottom of the chart, with three institutions awarding only one degree each and one awarding none. This visual pattern clarifies the magnitude of the disparity more intuitively than the table alone, illustrating how sharply the outcomes diverge across institution types. The chart also highlights the narrow overall scale of degree completion, reinforcing that, even where Black women do persist to graduation, the absolute numbers remain extremely low across both HBCUs and PWIs.

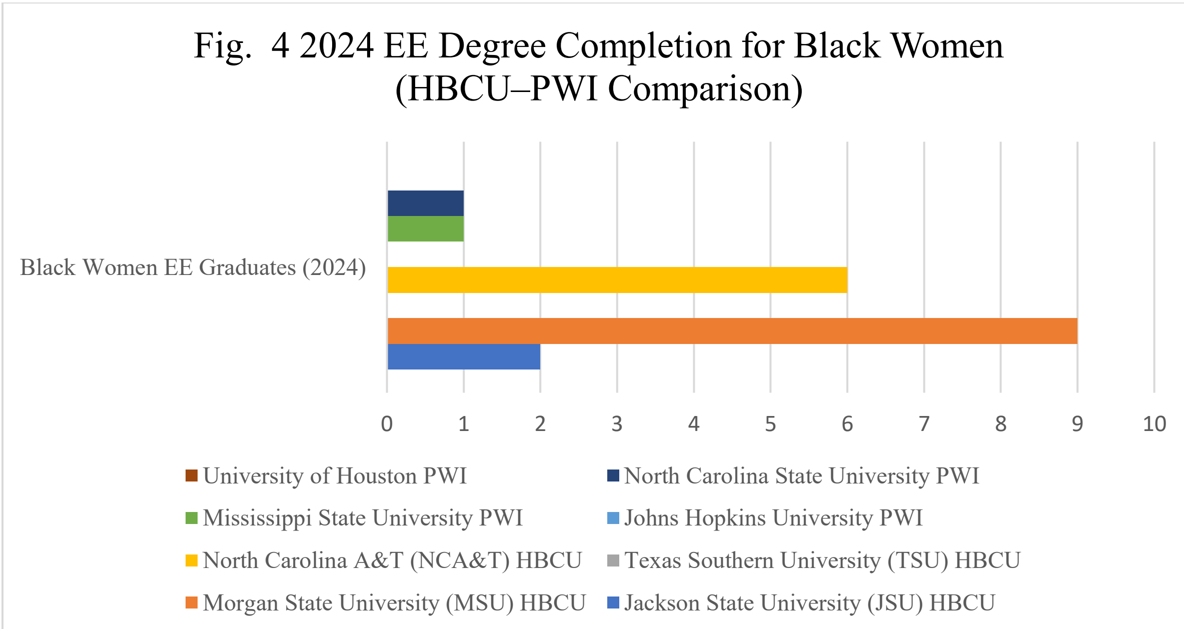

Fig. 4 2024 EE Degree Completion for Black Women (HBCU–PWI Comparison)

Graduation and Post-Graduate

To complete the pipeline analysis, Table 7 summarizes graduation and early career indicators for Black women in engineering. These measures highlight degree attainment, workforce entry patterns, and salary disparities, illustrating how inequities persist beyond college and continue into the professional stage of the STEM pathway.

Table 7: Graduation and Post-Graduate Outcomes

Metric	Value			
% of engineering degrees awarded to Black women (2016) [15]	4.62 % of women's engineering degrees			
HBCU contribution to Black women EE grads (2016) [15]	17.4%			
Top HBCU % awarded Black females EE Doctorate degrees (2013-2017) [15]	16%			
% of employed Black females as Scientist and Engineers [15]	>25 and younger	30-39	40-49	50-75
	14.7%	27.9%	26.1%	31.2%
Median annual salary for Black women engineers [15]	>25 and younger	30-39	40-49	50-75
	64k	85k	98k	N/A

The data pulled from the report “Top baccalaureate institutions of Black or African American engineering doctorate recipients, by sex: 2013-2017” shows degrees conferred for Black females from the “Top 12” institutions [26]. There are six PWIs and an equal amount of HBCUs on the list. The HBCUs awarded 16% and the PWIs 13.35% recipients. HBCUs represent a small fraction of U.S engineering doctoral-granting institutions [27], yet they produce a higher percentage of all Black female engineering doctorates in the U.S than PWIs. Within the “Top 12” institutions, HBCUs contribute over half of all female engineering doctorate recipients. This demonstrates the outsized role of HBCUs in producing Black women with advanced engineering degrees. Table 7 lists the percentage of employed Black females in engineering and their median annual salary. Black women are one of the multiply marginal underrepresented groups in undergraduate engineering education. This continues after graduation into the industry. For one group listed in Table 7—ages 30-39, the median salary for Latino, Black, and White females working in an engineering occupation is 95k, 85k, and 90k, respectively. The Black females in this group are earning 10k less than Latino and 5k less than White females.

Comparison of MSI and PWI Outcomes for Black Women in Engineering
To contextualize institutional variation in persistence and degree completion, Table 8 summarizes key differences in engineering outcomes for Black women at Minority Serving Institutions (MSIs) and Predominantly White Institutions (PWIs).

Table 8: Comparison of MSI and PWI Outcomes for Black Women in Engineering

Outcome Metric	MSI (e.g., HBCUs, HSIs)	PWI	Interpretation
Share of Black women earning STEM degrees	MSIs produce a disproportionately high share of Black women STEM graduates (e.g., HBCUs produced 46% of Black women STEM degree earners in one decade)	PWIs produce the majority of degrees overall but a much smaller proportion of Black women STEM graduates	Highlights MSIs’ outsized role in STEM equity
Engineering retention rates	Higher retention for Black women due to culturally responsive support, mentoring, and belonging cues	Lower retention; climate issues and isolation more frequently reported	Consistent with qualitative themes (support systems, mentoring)
EE-specific persistence	More supportive environments but still lower persistence in EE relative to other engineering majors	EE persistence is lowest among engineering disciplines for Black women	EE remains a high-attrition field across institution types
STEM identity development	Stronger identity affirmation and community support	Weaker belonging cues; higher reports of stereotype threat	Aligns with prior qualitative findings
Access to mentoring	More accessible faculty and peer mentoring networks	Mentoring often inconsistent or informal	Reinforces “accessibility to mentors” theme

Outcome Metric	MSI (e.g., HBCUs, HSIs)	PWI	Interpretation
Post-graduation outcomes	Strong early-career placement for those who persist; MSIs often provide targeted career support	Broader employer networks but persistent racialized salary gaps	Reflects national NCSES and ASEE trends

Although the quantitative indicators used to construct the Broadening Participation Pipeline Tracker are drawn from tables 2–4 and 6–7, we also incorporated Table 8 to contextualize institutional variation in engineering outcomes for Black women. While Table 8 does not supply numerical inputs for the Sankey visualization, it enriches the interpretive framework by highlighting structural differences between MSIs and PWIs that align with the qualitative themes and help explain the broader institutional landscape in which the pipeline operates. With the structural framework established and the data sources fully documented, the next section presents the Sankey visualization that quantifies progression, attrition, and institutional variation across the electrical engineering pathway.

Results

The results of the quantitative analysis are presented through the fall-off chart and Sankey visualization constructed from the stage-aligned indicators in tables 2–4, 6-7. These visualizations operationalize the five sequential stages of the Broadening Participation Pipeline Tracker and quantify the progression and attrition patterns observed across the electrical engineering pathway.

Fall-Off Points

We initially attempted to calculate fall-off values directly from national datasets; however, the available indicators were not sufficiently disaggregated by race, gender, and discipline to support this approach. As a result, all fall-off values used in the Tracker were derived from the curated, stage-aligned indicators compiled in tables 2–4 and 6–7. Table 9 summarizes the derived fall-off values used to construct the visualizations. These values were calculated by comparing the proportion of students progressing between sequential stages in tables 2–4 and 6–7, providing a clear numerical representation of where the most substantial losses occur across the pathway. Each fall-off point reflects the percentage-point difference between the share of students entering a stage and the share advancing to the next stage, based solely on the disaggregated data collected for this study. Fall-off values were computed using proportion progressing from stage i to stage j: Progression $_{i \rightarrow j}$ = (Nj/Ni) X 100 and the corresponding loss at each transition was calculated as: Loss $_{i \rightarrow j}$=100-(Nj/Ni) X 100 where N_i represents the number (or percentage) of students at stage i, and N_j represents the number (or percentage) of students at the subsequent stage j.

K–12 STEM exposure data were derived from NSF reports. STEM/EE-aligned intent was measured using YouScience career-cluster interest data. Electrical engineering enrollment, persistence, and degree completion data were obtained from IPEDS and institutional reports, which provide enrollment and completions disaggregated by race, gender, and institution type (HBCU vs. PWI). Fall-off points were calculated by comparing (1) STEM exposure →

STEM/EE-aligned intent, (2) intent → EE enrollment, (3) EE enrollment → EE persistence, and (4) EE persistence → EE degree completion.

Table 9: Fall-Off Points

Transition Stage	N_i(%)	N_j(%)	Progression (%)	Fall-Off (%)
K–12 STEM Exposure → STEM/EE-Aligned Intent	4.2	7.75	184.52	–84.52
STEM/EE-Aligned Intent → EE Enrollment	7.75	28.57	368.00	–268.00
EE Enrollment → EE Persistence	28.57	10.00	35.00	**65.00**
EE Persistence → EE Graduation	10.00	32.76	327.60	–227.60

Figure 5 presents the fall-off percentages associated with each transition stage, offering a concise preview of where the EE pathway narrows most sharply. This chart complements the numerical values in Table 9 by illustrating the relative magnitude of losses between stages. Negative values indicate pathway expansion, while positive values represent contraction. The most substantial contraction occurs between EE enrollment and EE persistence, where 65% of Black women exit the pathway before reaching degree completion.

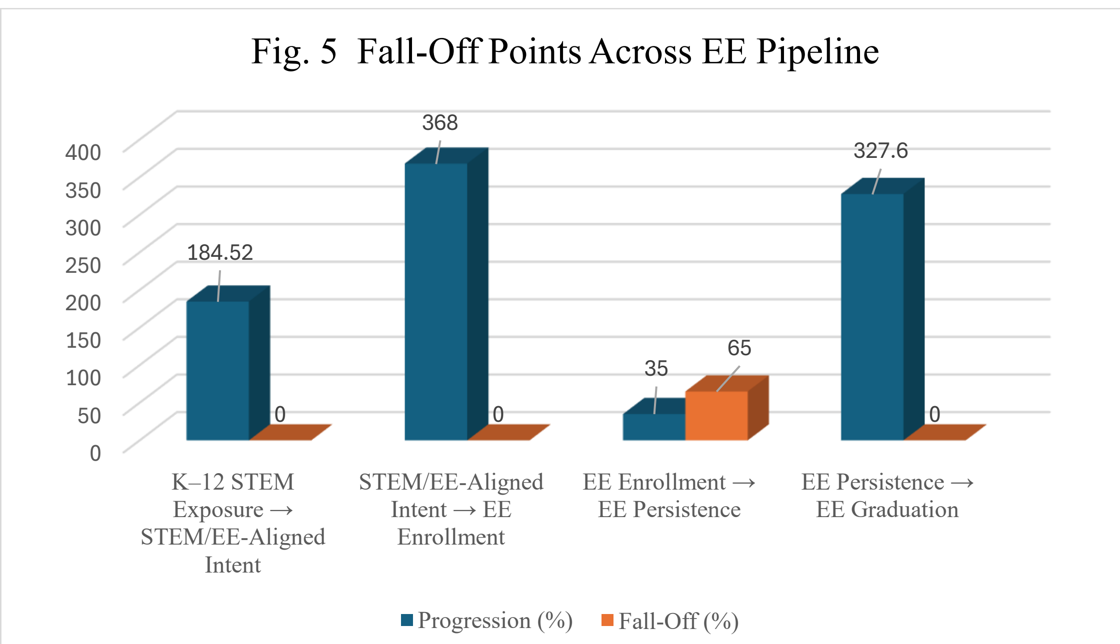

Fig. 5 Fall-Off percentages at each transition stage of the Broadening Participation Pipeline Tracker.

Broadening Participation Pipeline Tracker

The Broadening Participation Pipeline Tracker that we developed quantifies progression and attrition across the five sequential stages of the EE pathway for Black women. Using this model, we generated a Sankey diagram, figure 6, that scales flow widths according to progression values and annotates each transition with the corresponding N_i and N_j values for each stage. The

Sankey diagram displays these values at each stage because these nodes represent the structural inputs to the fall-off calculations and determine the width of each flow. We applied a red–green color scheme to the flows to explicitly distinguish contractions (red) from expansions (green), reinforcing the structural interpretation of each transition. While the fall-off chart summarizes percentage losses, the Sankey visualizes the underlying stage sizes and progression magnitudes. The first two transitions—K–12 STEM exposure to STEM/EE-aligned intent, and intent to EE enrollment—show apparent pathway expansion. This widening reflects the mismatch between narrow K–12 STEM coursework participation (e.g., AP STEM exam participation at 4.2%) and broader interest captured by career-cluster surveys (7.75%), as well as the shift in denominators between national interest surveys and discipline-specific enrollment counts. The most significant contraction occurs between EE enrollment and EE persistence, where only 35% of Black women who begin in EE remain on track toward degree completion, representing a 65% fall-off. The final transition, persistence to graduation, shows additional loss, with 32.76% of persisting students completing the degree. These patterns indicate that the pathway narrows most sharply after enrollment, underscoring the need for targeted retention and support strategies within EE programs. Taken together, the fall-off chart and the Sankey diagram we constructed depict a pathway that begins with early expansion but constricts substantially once students enter the major. These structural losses illustrate how few Black women progress through the full EE pipeline, even among those who initially express interest or enroll in the major. The quantitative patterns we identified establish the specific transition points where Black women are most likely to exit the pathway and provide a foundation for examining how these losses accumulate over time.

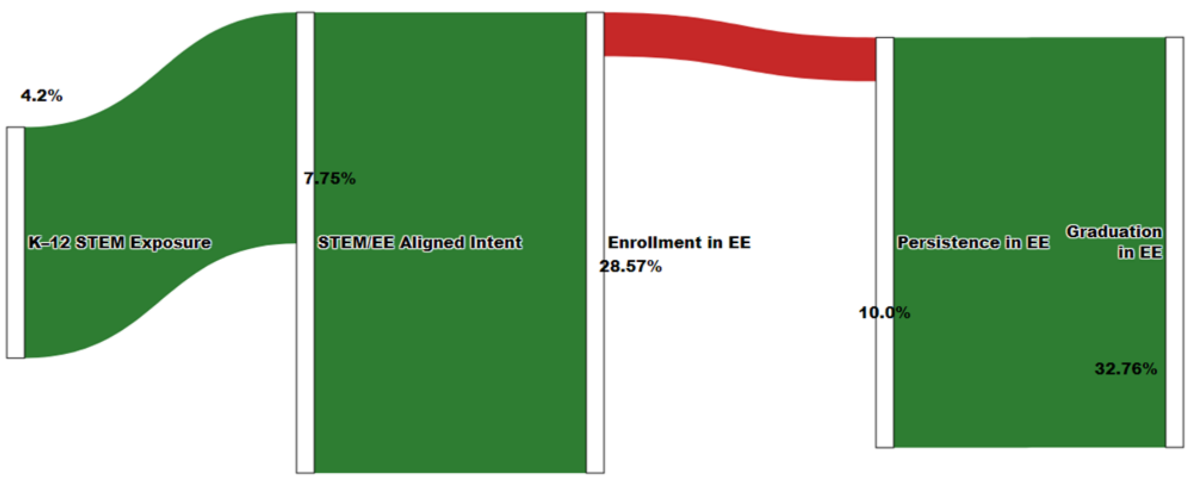

Fig. 6 Broadening Participation Pipeline Tracker

Conclusion

By linking national indicators to the qualitative themes we previously developed, our Broadening Participation Pipeline Tracker offers a mixed-methods foundation for identifying where targeted, equity-centered interventions may have the greatest impact. In constructing this model, we intentionally aligned the structural fall-off points with the lived experiences captured in our earlier qualitative study, allowing us to examine how the same pressures documented by participants manifest at scale in national data. The Tracker's stage-aligned structure offers a transparent method for identifying where losses occur and how they accumulate over time. The most substantial fall-off occurs prior to EE enrollment, with additional declines during persistence and degree completion, underscoring the need for interventions that span the full pathway. Since these patterns are derived from indicators specific to Black women, the findings highlight persistent structural barriers that continue to shape their underrepresentation in electrical engineering. Quantifying where Black women are most likely to exit the pathway and connecting these losses to documented lived experiences, our work establishes a data-driven foundation for designing actionable, equity-centered strategies. This integrated perspective positions the Tracker as both an analytical tool and a practical guide for institutions seeking to intervene at the points where Black women are most vulnerable to leaving the EE pathway.

Discussion

The structural patterns we observed in the Sankey visualization align closely with the five themes identified in our prior qualitative study—contributions to choosing engineering, difficulty of preparation, support systems, expectations and aspirations, and accessibility to mentoring. Although the present analysis does not directly measure these mechanisms, the fall-off points we identified mirror the lived experiences documented in our earlier work and offer a quantitative view of the same structural pressures. In our analysis, the most substantial narrowing occurs before EE enrollment**,** a pattern consistent with themes related to early exposure, uneven advising, and constrained access to rigorous preparation. Participants in the qualitative study described limited opportunities to explore engineering, inconsistent academic preparation, and a lack of guidance during key decision points—conditions that align with the early attrition reflected in the national indicators. The subsequent narrowing through persistence and graduation reflects themes tied to institutional climate, the availability of support systems, and the role of mentoring in sustaining aspirations. These later losses echo participants' accounts of isolation, limited faculty support, and challenges navigating the academic culture of engineering programs. Taken together, these patterns can be understood through a Cumulative Disadvantage Paradigm, a lens we apply to illustrate how early inequities compound over time, producing increasingly narrow pathways as students progress. The Tracker makes this compounding visible: early losses reduce the pool of Black women entering the major, and later losses further diminish the number who persist to degree completion. This structural reshaping of the pathway has direct implications for Black women's educational trajectories, access to engineering careers, and long-term representation in the field.

Future Work

Building on the structural patterns identified during our research, our next phase of research will integrate the fall-off points with the qualitative themes and sub-codes from our prior work to develop a mixed-methods synthesis of the barriers experienced by Black women in the EE pathway. This synthesis will allow us to connect the quantitative losses to the lived experiences, institutional conditions, and cultural dynamics that contribute to those losses. We plan to translate these insights into a set of actionable, equity-centered intervention strategies through a workshop or design-based research effort. Our goal is to ensure that the structural patterns revealed by the Tracker directly inform practical tools and supports for institutions seeking to strengthen retention and participation. Combining the structural indicators, we developed with the qualitative evidence we previously generated, this future work will move beyond identifying where losses occur to explain why they occur and how they can be prevented. Through this integrated approach, we aim to create a research-to-practice model that empowers institutions to intervene at the points where Black women are most vulnerable to leaving the EE pathway.

References

[1] L. Lattuca, P. T. Terenzini, and J. F. Volkwein, “Engineering Change: A Study of the Impact of EC2000,” ABET, 2006.

[2] National Science Foundation, “ADVANCE: Increasing the Participation and Advancement of Women in Academic STEM Careers,” NSF ADVANCE Program, 2022. [Online]. Available: NSF ADVANCE

[3] P. R. Moorer, “The Intersectionality of Black Women Engineering Students Attending a Predominantly White Institution,” Doctoral Dissertation, University of West Florida, 2022. [Online]. Available: UWF Repository

[4] National Science Foundation, NCSES, *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2019*, NSF 19-304, Mar. 2019. [Online]. Available: https://www.nsf.gov/statistics/wmpd

[5] National Science Foundation, NCSES, “Diversity and STEM: Women, Minorities, and Persons with Disabilities 2023,” NSF 23-315, Jan. 2023. [Online]. Available: NSF NCSES

[6] T. Fletcher et al., “Ignored Potential: A Collaborative Roadmap for Increasing African American Women in Engineering,” NSBE & SWE, 2021. [Online]. Available: NSBE Whitepaper

[7] L. M. Berhan and R. Kumar, “Comparative Study of the Intersection of Engineering Identity and Black Identity at a PWI and an HBCU,” *ASEE Annual Conference Proceedings*, Paper ID #22249, 2018. [Online]. Available: NSF PAR

[8] C. Haynes et al., “Toward an Understanding of Intersectionality Methodology: A 30-Year Literature Synthesis of Black Women’s Experiences in Higher Education,” *Review of Educational Research*, vol. 90, no. 6, pp. 751–787, Dec. 2020.

[9] L. Ong et al., “Inside the Double Bind: A Synthesis of Empirical Research on Undergraduate and Graduate Women of Color in STEM,” *Harvard Educational Review*, vol. 81, no. 2, pp. 172–209, 2011.

[10] J. Hall and T. Hall, “Undergraduate Engineering Education: Creating Space for Multiply Marginalized Students,” in 2024 ASEE Annual Conference & Exposition, Portland, Oregon, Autumn 2024. Available: https://peer.asee.org/48182

[11] J. DeJaeghere *et al.*, *Guidance Note on Qualitative Research in Education: Considerations for Best Practice*. United Kingdom Department for International Development, 2020. [Online]. Available: https://www.wwhge.org/wp-content/uploads/2025/03/Guidance-Note-on-Qualitative-Research-final2020.pdf

[12] I. Singh, "By the Numbers: Women in STEM," *Yale Scientific Magazine*, Nov. 2020. [Online]. Available: https://www.yalescientific.org/2020/11/by-the-numbers-women-in-stem-what-do-the-statistics-reveal-about-ongoing-gender-disparities/

[13] Higher Education Today, "HBCUs, Black Women, and STEM Success," May 2018. [Online]. Available: https://www.higheredtoday.org/2018/05/14/hbcus-black-women-stem-success/

[14] A. Miller and C. Brown, "Black Women in Higher Education: College of Engineering," *Center for Women, Gender and Global Leadership*, Howard University, Nov. 2023. [Online]. Available: https://cwggl.howard.edu/articles/black-women-higher-education-college-engineering

[15] **NCES, "Cell Suppression," National Center for Education Statistics. Available: https://nces.ed.gov/fcsm/dpt/content/3-2-2-1**

[16] National Science Board, Science and Engineering Indicators 2018. NSB 2018 1. Alexandria, VA: National Science Foundation, 2018. Available: **https://www.nsf.gov/statistics/2018/nsb20181/**

[17] National Science Board, *Science and Engineering Indicators 2018*, Appendix A: Technical Notes and Methodology. National Science Foundation, Alexandria, VA, 2018.

[18] "Report - S&E Indicators 2018 | NSF - National Science Foundation." https://www.nsf.gov/statistics/2018/nsb20181/report/sections/elementary-and-secondary-mathematics-and-science-education/high-school-coursetaking-in-mathematics-and-science#computer-science-and-technology-coursetaking

[19] M. Ewing, J. Wyatt, M. Iarrapino, and A. Jacklin, "AP® Precalculus: Who Participated and What We Learned in Launch Year," College Board Research, July 2025. Available: https://research.collegeboard.org/media/pdf/AP%20Precalculus%20Who%20Participated%20and%20What%20We%20Learned.pdf

[20] Westrick, Radunzel, & Bassiri (2018). *Leaning into STEM: Predicting STEM Major Choice Using Measures of Academic Tilt and Measured Interest Tilt.*

[21] YouScience & Black Girls Do STEM, 2024; NGCP, 2023

[22] "IPEDS Data Center." https://nces.ed.gov/ipeds/datacenter/Data.aspx?sid=e34b805d-9726-4ce8-a532-d013a05ec28f&rtid=1

[23] National Science Board, *Science and Engineering Indicators 2022*. NSB-2022-1. Alexandria, VA: National Science Foundation, 2022.

[24] National Science Board, *Science and Engineering Indicators 2020*. NSB-2020-1. Alexandria, VA: National Science Foundation, 2020

[25] NASEM, *Minority Serving Institutions: America's Underutilized Resource for Strengthening the STEM Workforce*. Washington, DC: The National Academies Press, 2019

[26] National Center for Science and Engineering Statistics (NCSES), "Women, Minorities, and Persons with Disabilities in Science and Engineering: 2019," *NSF - National Science Foundation*, Mar. 08, 2019. https://www.ncses.nsf.gov/pubs/nsf19304/data

[27] "HBCU schools offering engineering doctoral degrees." http://hbcu-colleges.com/engineering/doctoral