Quantitative Methodological Approaches to Understand the Impact of Interventions: Exploring Black Engineering Student Success

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Abstract

As engineering educators and practitioners, we must broaden the participation of students from racially minoritized populations to meet engineering education's social and ethical responsibilities to address problems and design solutions relevant to our diverse communities. However, the engineering profession in the United States has historically and continues to exclude certain racial and ethnic populations, including Black, Latinx, and Native people. As a result, engineering remains a predominantly white discipline despite national calls to broaden participation. There have been interventions to help historically excluded students navigate the exclusionary engineering culture, including institution-driven and student-driven interventions. Affinity engineering student organizations, such as the National Society of Black Engineers (NSBE), are student-driven and serve as effective interventions to help improve persistence and graduation rates for historically excluded undergraduate engineering students.

In this study, we explore different quantitative methodological approaches (logistic regression and survival analysis) to examine how various dimensions of involvement influence persistence. We consider a local chapter of NSBE at a large, Midwestern historically and predominantly white institution as a model student-driven intervention using a sample of 348 students. To understand how involvement in NSBE influences persistence, we define two dimensions of involvement within NSBE for our analysis: "time as a member" and "first-semester membership" as initial proxies for time invested and energy expended by Black engineering student members. We found a significant association between the length of time spent as a member of NSBE and the likelihood of graduation with an Engineering degree, highlighting the need for a depth of involvement. Interestingly, early involvement with NSBE was not associated with persistence to graduation in this study. The results provide less explored insights into the impact of different dimensions of a student-driven intervention on Black engineering student success and point to new quantitative methodological approaches that may be used for any intervention to understand its impact on student success. Next steps to expand on this work include adding more academic history control variables, increasing sample size, and examining institution-driven interventions as variables. This paper would be of interest to engineering educators, student support practitioners, institutional leaders, and all engineering stakeholders invested in understanding the broader ecosystem of student support, especially for interventions that serve historically marginalized students.

Introduction

In the United States, the engineering profession has historically and continues to exclude and marginalize certain racial and ethnic populations, including Black, Latinx, and Native people. The engineering profession was founded as a field of predominantly white men who have set the demographic, narrative, and cultural norms [1]–[4] to the detriment of the equity and inclusion ideals that leaders in the engineering field currently espouse [5], [6] and to the detriment of the social and ethical responsibilities of the engineering field to serving our diverse communities. The result of this foundational exclusion and its perpetuation is the phenomenon often referred to as "underrepresentation" of these racial and ethnic populations in engineering education programs and within the profession. For example, while Black individuals comprise around 12.5% of the US population, they make up only about 6.0% of first year undergraduate engineering student body in the US and only around 4.5% of the Bachelor degree awardees in engineering [6]. These representation numbers from 2021 (the most recently available data) reflect persistent "underrepresentation" that has remained almost unchanged over the past 20 years. Thus, engineering maintains its status as a predominantly white discipline despite national calls to broaden participation and diversity efforts at many levels. While "underrepresentation" often serves as the quantitative basis for many broadening participation efforts, these numbers are only *one* key status indicator – they only tell part of the story of demographic imbalance in engineering.

The historical and persistent exclusion seen in engineering is a multifaceted issue that has its roots in the dissonance between engineering culture and the cultural identities of those who have been historically excluded. Engineering culture can be defined as the knowledge, beliefs, and practices resulting in an "engineering way of thinking, doing, and being" [7]. The enactment of engineering culture is a major influence in how the field is perceived and how it is experienced. For many who have been historically excluded from engineering, engineering culture both implicitly and explicitly communicates that engineering does not align with their values or their cultural identities. They may turn away from engineering because they do not see themselves fitting into engineering spaces [5]. Furthermore, for individuals from historically marginalized racial and ethnic groups working towards a career in engineering, the culture often feels isolating and unwelcoming [8], diminishing their desire to continue in the field [9].

There has been a long history of implementing interventions to help historically excluded students navigate the exclusionary culture of engineering. Within the context of individual higher educational institutions, we categorize these activities as institution-driven interventions and student-driven interventions. Institution-driven interventions sit within the university infrastructure to support historically excluded groups to persist through engineering [10]–[12]. Prominent examples of institution-driven interventions for historically excluded racial and ethnic groups include minority engineering program offices (or their equivalents) and other types of diversity-focused engineering student support centers [13]. There are often symbiotic interactions between the support offered by institutional actors and student-driven interventions built by and for the students. Affinity engineering student organizations such as the National Society of Black Engineers (NSBE) and the Society of Hispanic Professional Engineers (SHPE) are notable interventions with strong student-driven components. Individuals from historically excluded groups find additional sources of community and the means to develop agency through local chapters of affinity engineering student organizations that center their racial and ethnic identities. This is in contrast to the dominant engineering culture that centers whiteness. By recognizing, affirming, and celebrating the race and ethnicity of historically marginalized students in an engineering context, these organizations may offer more welcoming cultural environments and help students manage some of the cultural dissonance they can experience within the dominant engineering culture [14], [15].

There has been the emergence of literature demonstrating that student participation in affinity engineering organizations, including collegiate chapter initiatives, serve as effective student-driven interventions to help improve persistence and graduation rates for historically excluded undergraduate engineering students [14], [16]–[21]. However, quantitative methods in the current corpus of research are somewhat limited to "all-or-none" analyses to participation in these organizations [18], [22]. As a first step to gaining further insight into how affinity engineering organizations (or other interventions) may influence student persistence, we explore insights and limitations of different quantitative methodological approaches to examine how various dimensions of involvement influence persistence using a local chapter of NSBE as a model student-driven intervention. Notably, NSBE is student-driven at the national and local collegiate chapter levels. We selected Black engineering students as our focus for this study given the flat or declining representation of Black students in engineering over the last twenty years and the documented cultural hostility experienced by Black students in engineering as demonstrated in prior qualitative and quantitative work [23], [24].

Educational theories that explore student involvement include Astin's theory of student involvement [25], Tinto's theory of student departure [26], [27], and specifically in engineering education, Lee and Matusovich's model of co-curricular support (MCCS) [13]. These theories point to structures that sit alongside the curriculum delivery and provide mechanisms that improve student outcomes, accounting for the environment in which they are delivered. Astin's theory helps us consider the time and energy students spend within an intervention and the environment in which it occurs. Student behaviors that suggest high student involvement can provide an explanatory link between participation in an intervention and a specific outcome, such as student retention. Another essential factor is students' transition from home and pre-college to campus and college education environments. In Tinto's theory of student departure [26], [27], students' perception of institutional fit within the social and academic systems of the university is a critical component of student retention. Grounded in empirical data from engineering student support centers that support undergraduate students from underrepresented groups (e.g., diversity engineering programs), MCCS reconceptualizes integration to focus on "student awareness and access to the resources that support success and retention" [28, p. 5], addressing interpretations of Tinto's model that to manage the cultural dissonance they may face students would need to assimilate to the dominant culture. MCCS also expands the concept of integration to include student interactions within social, academic, and professional subsystems in engineering education, as well as the broader university environment. One function of a NSBE chapter, like a diversity engineering program, is to increase members' awareness and access to resources that support their persistence within their degree programs. Combined, these theories help us hypothesize that the time and energy spent by NSBE members in chapter activities that support their social, academic, and professional integration in engineering education in culturally affirming ways will increase the likelihood they persist in engineering.

As an initial, yet limited proxy for time invested and energy expended on Black engineering student participation in a NSBE chapter, we considered participation in NSBE (paid chapter level NSBE member) and number of years of NSBE participation. Due to the importance of first-year transition, we also considered early participation in NSBE (participation in first semester). Through these analyses, we explore the following research questions:

RQ1: *To what extent do these dimensions of intervention involvement (participation in NSBE, number of years of participation in NSBE, and early participation in NBSE) influence whether Black students graduate from the Engineering degree program or leave without an Engineering degree?*

RQ2: *For those Black students who leave without an Engineering degree, how does involvement in NSBE influence persistence?*

Data Sources: Description of Sample

We analyzed historical cohort data and local NSBE chapter data for Black engineering students from a large, Midwestern historically and predominantly white institution (HPWI). To determine whether participation in NSBE is associated with whether Black engineering students complete a degree in Engineering at this institution or leave without one, a sample of 348 Black engineering students who entered between Fall 2003 and Fall 2014 was used. IRB-exempt institutional and NSBE chapter data was accessed through the NSBE chapter advisor and staff member. From Fall 2003, there was consistent NSBE chapter data collection coordinated between the chapter advisor and chapter officers. When we made the data request, Fall 2014 cohort data was the most complete dataset available to explore 6-year graduation rates. This dataset included only men and women as gender categories and our analyses reflect this binary representation. The majority of students in the sample were men (67 percent) and between the ages of 18 and 19. Of the total sample, 51 percent graduated with an Engineering Degree. Just under 40 percent of the total sample participated in NSBE with nearly two-thirds of them participating in their first semester[1]. It is noted that students who were still enrolled in an Engineering degree at the university at the time of data collection were not included in any of our analyses because their final outcome was unknown. Additionally, due to the very small number of students who entered the program at ages 17 years and 20 years, they were removed from further analysis to increase statistical power.

The characteristics of the Black Engineering students based on whether they graduated with a degree in Engineering or not are presented in Table 1.

Table 1: Demographics by Students who Did Not Finish (DNF) the Engineering Degree vs Graduated with an Engineering Degree

[1] Standard deviation is reported in parentheses

Characteristic	DNF, N = 170[1]	Graduated, N = 178[1]
Women	32%	34%
Age (years)	18.28 (0.45)	18.20 (0.40)
Participated in NSBE	28%	50%
No. of Years in NSBE	0.47 (0.91)	1.22 (1.50)
Participated in First Semester	18%	31%

[1] % ; Mean (SD)

Methodology

We use two approaches (logistic regression and survival analysis) to build quantitative models of the data described above and explore the impact of the dimensions of this student-driven intervention on persistence and graduation. The following sections describe the approaches in detail.

Logistic regression

Logistic regression is an analytical method that is used when the dependent variable is binary (e.g. yes or no), and the independent variables may be either quantitative or qualitative [29]. The parameter estimates of the logistic model allow for the calculation of odds ratios. If the ratio is positive, then the odds of the event happening increases. A value less than 1 suggests a reduction in the odds of the event occurring. This method has been used to examine degree completion and retention by students with disabilities [30], graduate students [31], [32], and undergraduate students [33], [34].

In this paper, the students in our dataset either graduated with a degree in Engineering from this institution (coded as 1) or is no longer in an Engineering degree program at this institution (coded as 0). The model will include age and gender as control variables, while examining one of three NBSE-related variables: (i) participation in NSBE; (ii) if the student participated in NSBE in the first semester; (iii) the number of years the student participated in NSBE.

Survival Analysis

Survival analysis is usually used in health situations and the dependent variables is the length of time before a patient "dies". The aim is to determine the factors (e.g. demographic variables, treatments) that influence the length of time persons survive after being diagnosed with a condition. This family of methods is suitable in helping to determine the factors which are associated with students' persistence in a degree program because it allows for different groups of students to be compared and the risk of a student leaving (analogous to a patient dying in a health scenario) can be estimated for each semester or academic year [35]. The methodology has also been used to examine the length of time undergraduate students spend in university degree programs [36]–[38].

In our paper, the dependent variable is the length of time a student stays at the university before leaving without an Engineering degree. As with the logistic regression, the same NSBE-related and control variables are used. Only students who are known to have left the university without a degree in Engineering are included in this analysis.

Two types of survival models are considered. The first is the Kaplan-Meier model, which is a nonparametric, univariate approach to analysing survival times [39]. Using this model, each independent variable may be analysed separately. The Kaplan-Meier model is best used with categorical independent variables such as whether the student participated in NSBE or if they participated in NSBE in their first semester.

To determine if the variable makes a significant difference in the length of time students spend at the university before leaving without an Engineering degree, the Log Rank test is used [40]. A p-value of 0.05 or less means that there is a significant difference in the time students spend in the Engineering degree program at the university and it is used in conjunction with a plot of the survival curves to determine which group spends the longer time. The higher curve represents the group spending more time in the program before exiting. The median time each group spends in the program is also calculated.

The second model, the Cox Proportional Hazard regression model, is also used to analyse the same dataset. This semiparametric model allows for the inclusion of more than one independent variable irrespective of whether it is categorical or quantitative [41]. In this model, each of the three NSBE-related variables is included with age and gender.

In our survival analysis, we use hazard ratios to compare the likelihood of a student who participated in NSBE leaving the university without an Engineering degree with that of a student who did not participate in NSBE for a specified period. This ratio is assumed to be constant over time in the Cox Proportional Hazard model and is adjusted for all other variables in the model. If the hazard ratios are equal to one, it means that there is no difference between the treatment and control group. If the ratio is greater than one, it means that the treatment group experiences the event with a higher probability than the control group in a given period. The converse is true if the ratio is less than one. Confidence intervals for each estimate are also presented for the hazard ratios for each independent variable. If the lower confidence limit is less than one and the upper confidence interval is greater than one for a given estimate, then the ratio is not considered to be significantly different from one. This means that there is no difference in the length of time a student who received the treatment versus one that was in the control group.

All analyses were conducted using R version 4.2.0 [42], and the following R packages for survival analysis: survival [43]; survminer [44]. An independent variable with a p-value of 0.05 or less is considered significant for all models.

Results

RQ1: To what extent do these dimensions of intervention involvement (participation in NSBE, number of years of participation in NSBE, and early participation in NBSE) influence whether Black students graduate from the Engineering degree program or leave without an Engineering degree?

Logistic regression models were created to determine if students who participated in NSBE had statistically significant higher odds of graduating with a degree in Engineering. Three logistic regression models were developed. The dependent variable for all logistic models (Models 1 – 3) is binary, where 1 = the student graduated with a degree in Engineering and 0 = the student left the institution without a degree in Engineering.

The first model was used to determine if participation in NSBE at any point (Yes/No) is associated with graduation from the university with a degree in Engineering (n = 348). Additionally, age and gender are used as control variables. The results show that students who are members of NSBE at some point during their tenure, have a 161% (=(2.61 – 1) * 100) increase in the odds of graduating with a degree in Engineering (Table 2 – Model 1). These odds are statistically significant (p = 0.00003), unlike the control variables.

We used Model 2 to ascertain if early participation has any association with graduation or not. Only students who were members of NSBE were included in this analysis (n = 136), with the variable of interest being whether students participated in NSBE in their first semester of entering the program. The same control variables were used. Participation in NSBE in the first semester was not significantly associated with graduation (p = 0.811) (Table 2 – Model 2).

Given the significant relationship in Model 1, the third model examined whether the length of time spent in NSBE was associated with graduation. As with Model 2, only students who participated in NSBE are used in this analysis, and age and gender were again used as control variables. Model 3 results show that for every one-year increase in the student being a member of NSBE there is an 86% increase in the odds of graduating (=(1.86 – 1)*100) (Table 2 – Model 3).

Table 2: Logistic Regression Results

Dependent Variable:	**Graduated with an Engineering Degree = 1 / Did Not Graduate with an Engineering Degree = 0**								
	Model 1			*Model 2*			*Model 3*		
Predictors	*Odds Ratios*	*CI*	*p*	*Odds Ratios*	*CI*	*p*	*Odds Ratios*	*CI*	*p*
(Intercept)	0.81	0.58 – 1.13	0.218	2.59	1.31 – 5.43	0.008	0.68	0.28 – 1.61	0.384
Age Group (Ref. = 19 Years)	0.63	0.38 – 1.05	0.076	0.63	0.27 – 1.49	0.285	0.72	0.30 – 1.76	0.465
Women	0.98	0.62 – 1.57	0.947	0.69	0.33 – 1.43	0.316	0.65	0.30 – 1.41	0.274
Member of NSBE (Ref. = Yes)	**2.61**	**1.67 – 4.12**	**<0.001**	-	-	-	-	-	-
Member of NSBE in 1st Semester (Ref. = Yes)	-	-	-	0.91	0.42 – 1.93	0.811	-	-	-
No of Years a Member of NSBE	-	-	-	-	-	-	**1.86**	**1.31 – 2.76**	**0.001**
Observations	348			136			136		
R^2 Tjur	0.061			0.018			0.106		

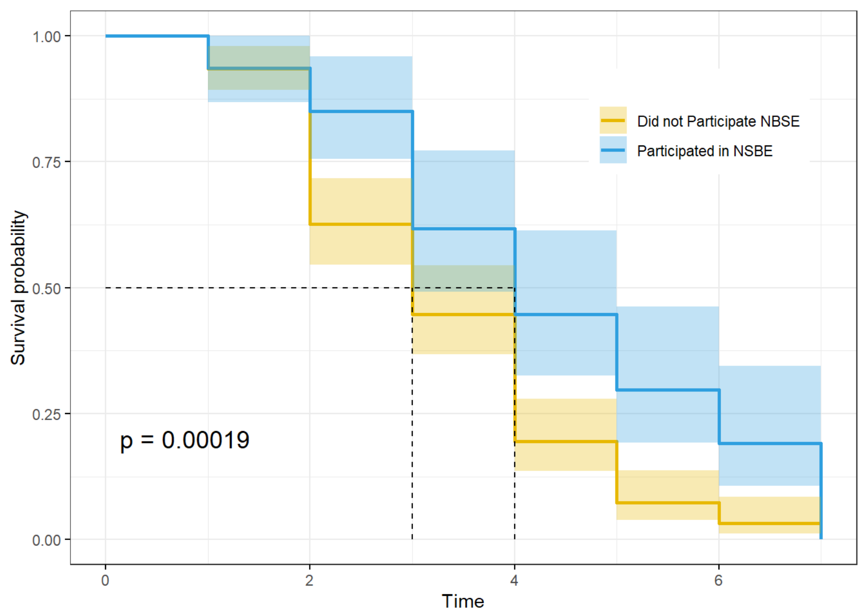
RQ2: For those Black students who leave without an Engineering degree, how does involvement in NSBE influence persistence?

As mentioned in the methodology, only students who did not graduate with an Engineering degree are included in the survival analysis. Our goal is to determine the length of time students remain enrolled in Engineering prior to leaving.

In general, the median length of stay in the Engineering degree program for students who did not participate at all in NSBE is 3 semesters, while the median time for those who participated in NSBE is 4 semesters.

The Kaplan-Meier analysis shows that there is a significant difference between the time spent in the Engineering degree program by students who did not participate in NSBE and students who did, with the latter staying longer ($p = 0.00019$). As shown in Figure 1, those who participated in NSBE, represented by the higher blue curve, have higher probabilities of staying in the Engineering program, when compared to those who did not participate in NSBE, represented by the lower yellow curve.

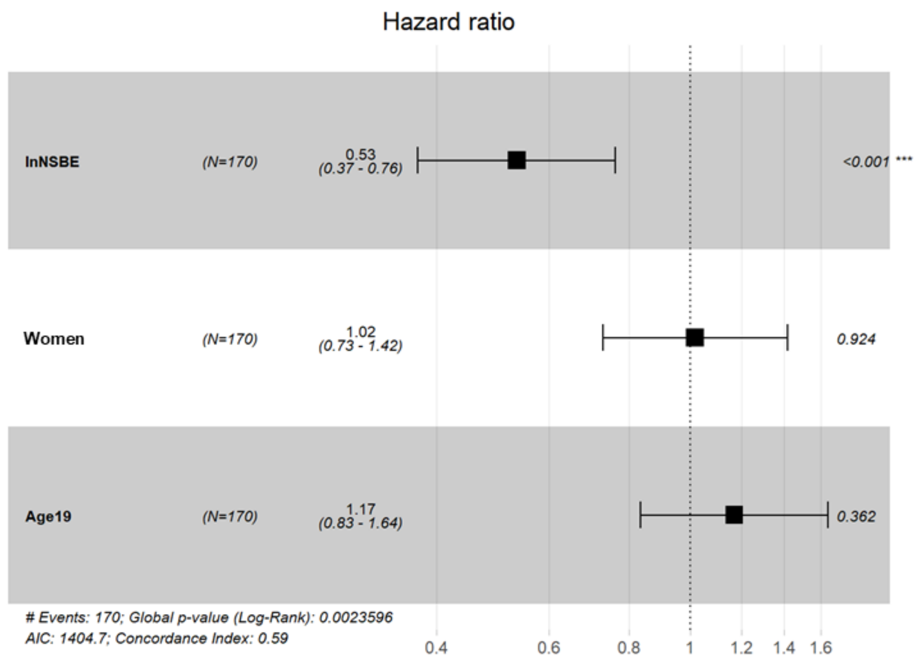
Figure 1: Kaplan-Meier Survival Curves – Participation in NSBE (Yes/No)



The Cox Proportional Hazards Model was analysed with gender (reference group = women), age group (reference group = 19 years) and whether the student was a member of NSBE or not. Again, the dependent variable is the time taken to leave the Engineering degree program without graduating with this degree.

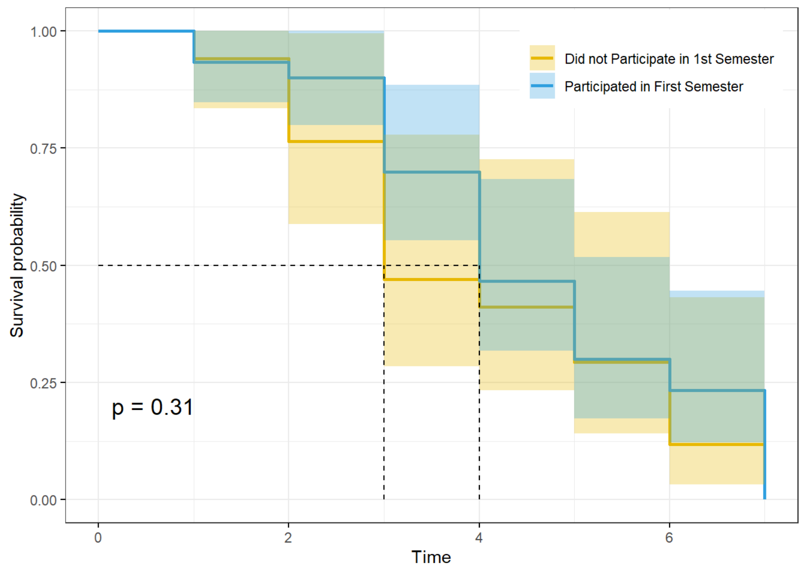
The results show that while gender and age group are not significant, students who participated in NSBE have a significantly lower probability of leaving the Engineering program in a given semester, when compared to those who did not participate in NSBE ($p = 0.00055$) (Figure 2). The hazard ratio of 0.53 means that the odds of students leaving the university without an Engineering degree in a given semester is almost two times (=1/0.53) higher for those who did not participate in NSBE. In other words, students who participate in NSBE are almost 50% less likely to leave in a given semester than those who do not.

Figure 2: Cox Proportional Hazard Model – Participation in NSBE (Yes/No), Women, Age 19



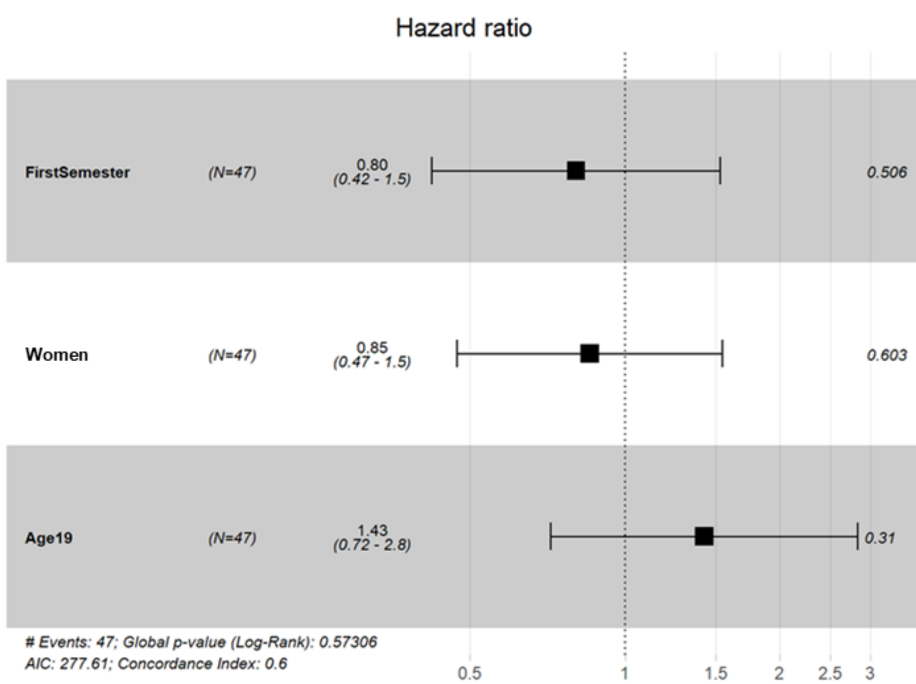
The Kaplan-Meier survival analysis method was also used to determine if participating in NSBE in the first semester resulted in a significantly longer time before persons left the university without a degree. Of the 136 students who were in the Engineering program, only 47 did not graduate with an Engineering degree and participated in NSBE. Based on this subset, there was no significant difference in the probability of leaving without an Engineering degree at any given time ($p = 0.31$). Additionally, as shown in Figure 3, the plot of the Kaplan-Meier survival functions shows an overlap in the curves for those who participated in NSBE in their first semester and those who did not.

Figure 3: Kaplan-Meier Survival Curves - Participated in NSBE in First Semester



The Cox Proportional Hazard analysis which controlled for gender and age, showed no evidence that participation in NSBE in the first semester has an effect on the length of time that a student remains in the program before leaving without a degree in Engineering (p = 0.506) (Figure 4).

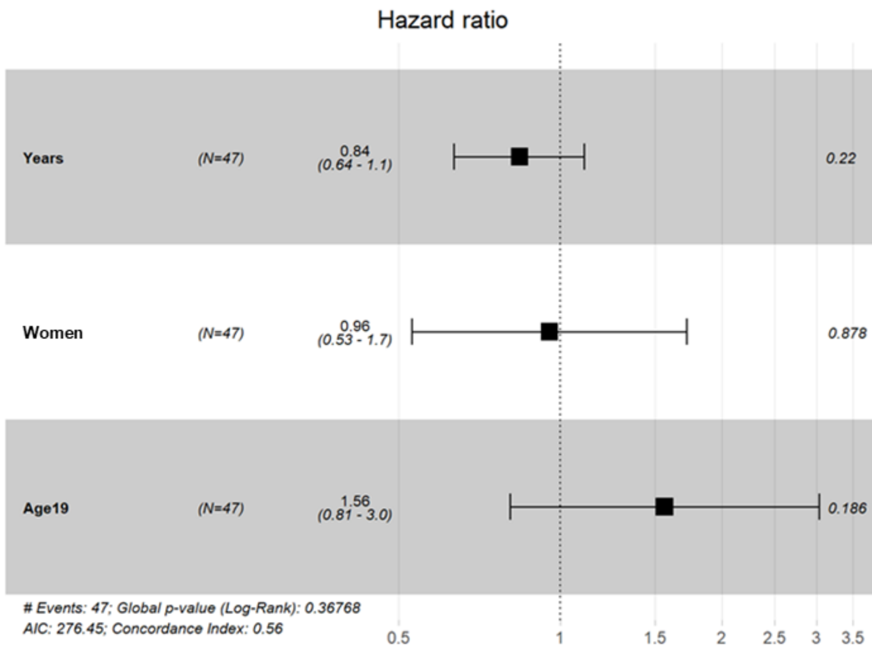
Figure 4: Cox Proportional Hazard Model - Participated in First Semester (Yes/No), Women, Age 19



Finally, the number of years students participated was also analysed to determine if the number of years a student spent in NSBE was related to the length of time a student remained in Engineering at this university. Given that the independent variable in this case is quantitative, only a Cox Proportional Hazard model was analysed.

As with participation in NSBE in the first semester, there was no evidence that the number of years a student spends in NSBE is related to the length of time a student remains enrolled before leaving the university without a degree in Engineering (p= 0.22) (Figure 5).

Figure 5: Cox Proportional Hazard Model – Number of years in NSBE, Women, Age 19



In summary, participation in NSBE and the number of years that they participated in NSBE are significantly associated with whether Black engineering students from a large, Midwestern HPWI graduate with an Engineering degree. Furthermore, for Black engineering students that leave without a degree in Engineering, participation in NSBE lengthened their median time of stay in the program by one semester and NSBE members were almost 50% less likely to leave in a given semester than those who did not.

Limitations

The variables we had access to in this dataset, gave limited information on the students' academic history. Therefore, we could not control for other potentially meaningful factors, such as academic indicators. This could have contributed to the low discriminating power, represented by the Tjur R-Squared, which measures the goodness of fit of the model [45].

Another potential limitation is the small sample size (n = 47) of students who were members of NSBE but did not complete their Engineering degree at this university for the survival analysis. A larger sample size would increase the power of the model and allow for more concrete conclusions.

Furthermore, this study is focused on Black engineering student participation at one HPWI, so inferences of Black engineering student persistence following similar trends at other institutions or institutional contexts are limited.

Additionally, other variables of interest that could help us explore levels of involvement in more nuanced ways are not part of current archival records. Opportunities for future data collection exploring NSBE chapter involvement include participation in specific programs, activities, and services offered by the chapter and student involvement in leadership positions at the organization's chapter, regional, and national levels.

Discussion

The purpose of this study was to employ quantitative methods to explore how different dimensions of an intervention for historically excluded populations may impact persistence and graduation of students. The specific analysis within this study gives an exploratory quantitative perspective on the relationship between Black engineering students' participation in NSBE (a student-driven intervention) and graduation or persistence in an Engineering degree program at a HPWI.

As with many studies in this space, at a high level, our results align with Astin's theory of student involvement [25] Tinto's theory of student departure [26], [27], and the Model of Co-Curricular Support [13] which suggest that higher levels of student involvement and greater connection with the institution improve student persistence. In our study, we explore one specific intervention (a NSBE chapter) more deeply by defining two additional dimensions of involvement within that specific intervention. First, we use "time as a member of NSBE" as a proxy for "higher level of involvement". Additionally, we use "first-semester NSBE membership" as a proxy for "early involvement". Prior work has demonstrated that participation in NSBE and other affinity engineering organizations is associated with greater persistence of historically excluded racial and ethnic groups [14], [16]–[20]. Building on that work, we additionally found a significant association between the length of time spent as a NSBE member (higher level of involvement) and the likelihood of graduation with an Engineering degree at this particular institution. This underscores that there is a depth of involvement that is needed for this intervention to be effective for persistence to graduation. Practically, this observation may be applicable to other interventions as well. Interestingly, we did not find an association between "early involvement" with NSBE as defined by "first semester NSBE membership" and graduation with an Engineering degree in this study. On its face, this quantitative finding suggests that establishing early community in this specific local NSBE chapter is not associated with persistence to Engineering degree. However, as noted in the introduction, there are often symbiotic interactions between institution-driven and student-driven interventions. There is potentially a pathway from other early community-building interventions that lead into NSBE. Further, refinement of the "early involvement" definition, along with consideration of other interventions in the model, may yield additional insights into this phenomenon.

In this study, we also use survival analysis as a method to probe how the dimensions of involvement in an intervention impact student persistence among those who eventually leave. Survival analysis offers a powerful set of statistical techniques derived from the medical field that, when applied to education, enable the examination of attrition patterns of students. Our primary findings from this analysis are that, among the Black students who don't graduate with an Engineering degree, NSBE members tended to stay longer in their academic program before leaving. The other dimensions of involvement in the intervention (length of time as a member and early involvement) have no significant impact on this measure. While survival analysis could be applied to the entire population of students to assess the overall risk of leaving engineering, we investigated persistence time for those who did leave engineering. One may ask, "Why do we care about the impact of an intervention if someone eventually leaves engineering?" We posit that this type of analysis offers greater insight for further qualitative study of the intervention to understand why student involvement and deeper engagement in NSBE may lengthen their stay at an institution. Qualitative analyses could inform how educators may focus efforts to increase the likelihood that Black Engineering students graduate with their desired degree as there is a longer window of time to intervene. Further, the analyses provide information on when the risk of leaving is highest, which offers opportunities for more targeted interventions.

The results of this study provide a more granular view of the impact of different dimensions of a student-driven intervention (a NSBE chapter) on the persistence and graduation of Black Engineering students. The analyses provided offer new insights into how the length of involvement with NSBE is significantly associated with the graduation of Black students with Engineering degrees and that involvement in NSBE extends the time before leaving Engineering for those who do decide to leave. Beyond the new information on Black Engineering student success offered here, this study points to different quantitative methodological approaches that may be used for any type of intervention to understand its impact on student success. Further work to build from the methods and results from this study will include: adding more control variables to the quantitative model including previous academic history; increasing sample size with additional cohort data made available since the beginning of this study; adding institution-driven interventions into the model such as involvement in diversity Engineering programs; and mixed methods studies to gain greater insights into our findings.

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