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Pathways of opportunity in STEM: comparative investigation of degree attainment across different demographic groups at a large research institution

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Abstract

Background We used an opportunity gap framework to analyze the pathways through which students enter into and depart from science, technology, engineering, and mathematics (STEM) degrees in an R1 higher education institution and to better understand the demographic disparities in STEM degree attainment.

Results We found disparities in 6-year STEM graduation rates on the basis of gender, race/ethnicity, and parental education level. Using mediation analysis, we showed that the gender disparity in STEM degree attainment was explained by disparities in aspiration: a gender disparity in students' intent to pursue STEM at the beginning of college; women were less likely to graduate with STEM degrees because they were less likely to intend to pursue STEM degrees. However, disparities in STEM degree attainment across race/ethnicities and parental education level were largely explained by disparities in attrition: persons excluded because of their ethnicity or race (PEERs) and first generation students were less likely to graduate with STEM degrees due to fewer academic opportunities provided prior to college (estimated using college entrance exams scores) and more academic challenges during college as captured by first year GPAs.

Conclusions Our results reinforce the idea that patterns of departure from STEM pathways differ among marginalized groups. To promote and retain students in STEM, it is critical that we understand these differing patterns and consider structural efforts to support students at different stages in their education.

Keywords Demographic disparities, Mediation analysis, Opportunity gap, Persistence, STEM inequities, Structural equation modeling

Introduction

Several structural inequities and systems of oppression have prevented historically and currently excluded demographic groups from flourishing in higher education in science, technology, engineering, and mathematics (STEM). For example, due to legacies of discriminatory policies in the United States, students from certain regions and ethnic groups are more likely to attend under-resourced schools (Reardon, 2013). Students from schools with few educational resources are less academically prepared for higher education than their peers from well-resourced high schools (Aikens & Barbarin, 2008; Ferguson et al., 2007). Excluded students who enter higher education face discrimination amid chilly classroom and campus climates (Dewsbury & Brame, 2019; Harrison & Tanner, 2018) and lack relatable

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role models among faculty and in curricular materials (Damschen et al., 2005; Phillips & Hausbeck, 2000; Wood et al., 2020).

The conditions and obstacles that some students experience lead to educational achievement disparities in introductory college courses (Salehi et al., 2019; Theobald et al., 2020), differential rates of graduating with a STEM degree (Seymour & Hunter, 2019), and underrepresentation in the scientific workforce. The literature establishes that achievement disparities are highly correlated with skin color, ethnicity, linguistic competence, and social class status (e.g., Salehi et al., 2019). However, to focus on achievement gaps downplays structural inequities and suggests that students are solely responsible for improving their own educational outcomes. Primarily focusing on student achievement leads to policies that emphasize high-stakes assessments in schools and 'gaps' in performance outcomes. These policies attempt to fix groups of students rather than alleviate the challenges they face and provision future students. An 'opportunity gap' framework "shifts our attention from outcomes to inputs" (Carter & Welner, 2013, p. 3), focusing on structural deficits in the broader systems in which students learn, such as institutions, classrooms, and teaching norms, that produce significant differences in test scores, grade point averages, and STEM degree attainment. Applying this framework promotes re-envisioning higher education as an 'engine for social mobility' (Salehi et al., 2020, p. 12).

National calls to support marginalized demographic groups in STEM highlight the growing need to address opportunity gaps in higher education (Olsen & Riordan, 2012). Several studies have investigated factors that contribute to the retention of marginalized students in STEM programs (Chen, 2013; French et al., 2005; Hall et al., 2015; Maltese & Tai, 2011; Marra et al., 2012; Rask, 2010; Shaw & Barbuti, 2010; Zhang et al., 2004) and identify different components of the academic environment that help students remain in STEM, including smaller class sizes, undergraduate research opportunities, exposure to active learning, effective academic advising, peer mentoring opportunities, and explicit instruction on self-regulated learning (Ewell et al., 2022; Xu, 2016; reviewed in Sithole et al., 2017). The impact of promising classroom and curricular interventions at institutions of higher education, however, can be hampered by structural challenges faced by students before entering college. For example, if inequities that occur before college divert students from pursuing STEM degrees, changes to university STEM programs will not retain students who never enrolled in the first place.

The current work is a quantitative study focused on disentangling whether disparities in attaining STEM degrees are due to (1) disparities in aspirations to study STEM at the beginning of college or (2) disparities in rates of attrition during college. We further explore the role of pre-college STEM education quality in shaping disparities in aspiration for and/or attrition from STEM. The goal of this study is to employ an opportunity gap framework to identify barriers and opportunities for successful systems-level interventions aimed to address demographic disparities and contribute to a more inclusive STEM education. Systems-level interventions are evidence-based efforts to promote success among students that can occur at the classroom level, the institutional level, or in administrative or extra-curricular contexts. Our focus is specifically on groups marginalized in STEM, which we broadly define to be any group of people that self-identify as underrepresented, marginalized, or oppressed according to any dimension(s) of their identity. Using an expansive dataset from a public, research-intensive institution in the United States encompassing students across mathematics, physics, chemistry, geosciences, biology, and engineering, we test four explicit hypotheses to identify where opportunity gaps result in demographic disparities in STEM degree attainment. Two of our hypotheses investigate whether disparities in degree attainment are due to differences in aspiration, and the other two investigate whether these disparities are due to demographic differences in attrition.

Hypothesis 1 (aspiration disparities) College students from marginalized demographic groups are less likely to receive undergraduate STEM degrees because these students enter college with a lower intent to pursue a STEM degree.

For students entering college, choosing to major in a STEM field is one of the initial steps toward attaining a STEM degree. A number of factors significantly influence students' initial interest in choosing a STEM major and consequently attaining a STEM degree, especially early STEM promotion by family members (Sjaastad, 2012; VanMeter Adams et al., 2014), positive prior experiences in STEM courses and/or STEM outreach programs (McGill et al., 2015; VanMeter Adams et al., 2014), and prior achievements in STEM (Maltese et al., 2014; Tai et al., 2006). The intent to pursue STEM can vary across demographic groups due to a myriad of disparities in opportunity. For example, role models, especially family members, in STEM fields are critical for seeding early interest in these fields, and marginalized demographic groups are less exposed to STEM role models. A lack of role models may be particularly challenging for first generation students, who have been shown to be less likely to pursue STEM (Anderson & Kim, 2006; Chen, 2005; Shaw & Barbuti, 2010). Furthermore, the quality of STEM education prior to college is not equal across demographic groups (Reardon, 2013; Salehi et al., 2019, 2020). Such societal opportunity gaps can deter interest in STEM fields for marginalized demographic groups and lead to disparities in aspiration to pursue STEM across demographic groups (Anderson & Kim, 2006; Chen, 2005; Shaw & Barbuti, 2010). Marginalized students are less likely to intend to pursue STEM when entering college, which in turn leads to a lower likelihood of graduating with STEM degrees (Anderson & Kim, 2006; Chen, 2005; Shaw & Barbuti, 2010).

Hypothesis 2 (aspiration disparities caused by gaps in pre-college education) College students from marginalized demographic groups are less likely to receive undergraduate STEM degrees because of gaps in high school preparation, which in turn leads to lower intent to pursue a STEM degree.

Whereas in Hypothesis 1 we examine student aspiration to pursue STEM regardless of their academic preparation, Hypothesis 2 emphasizes the quality of courses that students take in high school and students' academic preparation due, in part, to those courses. Previous studies show high school STEM courses are among the most influential factors that drive students' intent to pursue a STEM degree in college (Tyson et al., 2007; Wang, 2013). In Hypothesis 2, we examine how academic preparation impacts students' intent to pursue STEM. For example, high school physics plays an important role in the path to a STEM degree (Bottia et al., 2015; Tyson et al., 2007). However, fewer women elect to take high-level high school physics, and under-resourced high schools may not offer physics (Kelly & Sheppard, 2009; Krakehl & Kelly, 2021; Tyson et al., 2007). For this reason, we expect high school preparation to result in gender, racial, and generational differences among students intending to major in STEM.

Hypothesis 3 (attrition disparities caused by disproportionate academic challenges in the first year) College students from marginalized demographic groups are less likely to receive undergraduate STEM degrees due to opportunity gaps in introductory 'weed out' courses that impose disproportionate academic challenges to marginalized students.

Academic challenges faced during the first year can cause students to leave STEM fields and/or college altogether. During an undergraduate degree, students who do not excel in introductory STEM courses, relative to non-STEM courses, are more likely to switch majors (Chen, 2013). In fact, the performance challenge associated with large introductory STEM courses is the most frequently cited reason students leave their pursuit of STEM degrees (Seymour & Hunter, 2019). The challenge is exacerbated by many factors ranging from outdated and ineffective teaching (Freeman et al., 2014; Theobald et al., 2020), to chilly classroom climates (Rainey et al., 2019), to a lack of role models in curricular materials (Becker & Nilsson, 2022; Wood et al., 2020), to experiences of microaggressions and/or discrimination on the basis of identity factors (Harrison & Tanner, 2018; Lee et al., 2020; Salehi et al., 2021). Previous work has documented challenges in introductory STEM courses among LGBTQIA + students (Cooper & Brownell, 2016), students with disabilities (Gin et al., 2020), and students with hidden identities (Henning et al., 2019). We expect these opportunity gaps in first year college courses across demographic groups to lead to differential rates of leaving STEM majors (as in Hatfield et al., 2022).

Hypothesis 4 (attrition disparities caused by gaps in pre-college education) College students from marginalized demographic groups are less likely to receive undergraduate STEM degrees because of inadequate high school preparation, leading to disproportionate academic challenges in early undergraduate courses.

Hypothesis 4 adds to Hypothesis 3 by explicitly accounting for variation in high school preparation. Students' high school STEM preparation is linked to students' performance in early STEM courses (Hazari et al., 2007). More recent work has empirically established that high school STEM preparation is the primary mediating factor between demographic variables and performance in early STEM courses (Salehi et al., 2020). In Hypothesis 4, we test whether demographic disparities in academic performance in early college courses are due to differences in high school preparation. We further test whether these opportunity gaps in first year college courses caused by disparities in high school preparation explain demographic disparities in STEM degree attainment.

Methods

We used structural equation modeling to quantitatively analyze institutional enrollment and demographic data with the goal of identifying key locations along STEM pathways where structural inequities created demographic disparities in STEM degree attainment. Quantitative analyses on demographic variables can reinforce deficit thinking towards marginalized students and downplay the role of systemic discrimination, biases, and inequities (Zuberi, 2001; Zuberi & Bonilla-Silva, 2008). To avoid the misuse of quantitative analyses and to subvert deficit thinking, we approach our analyses and interpret our results through a critical quantitative approach by centering societal structures that harm individuals who are not White men from educated families (Gillborn et al., 2018; Pearson et al., 2022).

Positionality statement

Life experiences and identities held by researchers influence the research questions asked, the analytical choices made, and the interpretation of study results. We include our positionality to be upfront about our identities and to acknowledge the lenses through which we made research decisions (Secules et al., 2021). We are trained scientists with undergraduate degrees in STEM and PhDs in biology, engineering, and learning sciences. We identify as White cisgendered men and women. RAC, CJB, and EB were born and raised in the United States and SS immigrated to the US for graduate school. EB identifies as a member of the queer community. We represent a team of education researchers who believe every learner should be provided with equal educational opportunities to excel. We believe this will only be achieved through understanding systemic equity barriers and designing evidence-based solutions. However, we recognize our identities do not align with some of the groups of students that are the focus of the current research, placing limitations on the extent of overlap between our lived experiences. For example, our institutional recommendations may not address the breadth of unique challenges of students from different ethnic/racial groups, as they are drawn primarily from existing literature and not from our own experiences as people excluded due to those aspects of our identities.

Data

Data were collected from institutional enrollment records at a predominantly white, public, research-intensive institution in the southeastern United States dating from 2011 to 2021. Enrollment records included enrollment data for every student in every academic term and described students' incoming academic preparation, incoming declared major, undergraduate academic performance, and postsecondary degree completion. The institutional data about student identity is limited to discrete racial/ethnic categories, binary gender, and college generation status.

Enrollment record inclusion criteria

We analyzed records from 15,600 unique students. We only included students who enrolled between fall semester of 2011 and the summer semester of 2015. The former constraint ensures that we have the academic records (i.e., GPA) from students from their first year enrolled at the institution. The latter constraint ensures that all students in the data set had enough time to graduate within a period of 6 years. We chose to use a 6-year graduate window because this is the typical metric used by most institutions to measure student success (Bowen et al., 2011). Furthermore, there are many programs at this university (e.g., engineering) in which it is typical for students to take more than four years to complete a degree, even if they don't change their course of study at any point in that time frame. We also restricted our analyses to first-time-freshman students, removing students who had transferred to the university from another institution (typically a two-year college) and students who had previously received a bachelor's degree. Although understanding STEM degree attainment in these groups of students is important, these groups both face different sets of challenges compared to first-time freshman. We defer investigation of outcomes for these students to a future paper.

Major characterization in the sample

Students select a course of study at the time of application to this university. We created variables to classify students' incoming major based on this selection as either STEM or non-STEM. We took a broad definition of STEM, including engineering, mathematics, physics, chemistry, geoscience, biological sciences, nursing, forestry, agriculture, and wildlife ecology. We did not include social sciences such as psychology or economics. Our sample included 8,676 STEM majors and 6924 non-STEM majors.

Binary gender characterization in the sample

The sample included 7423 male students and 8177 female students. It is standard practice among higher education institutions in the United States to keep only records of biological sex and not of gender identity. We acknowledge that this metric does not adequately capture the spectrum of gender identity and erases the experience of students who do not identify as male or female. For the remainder of this paper, we will refer to female students as women and male students as men and will use gender to refer to this institutional measure of biological sex.

Racial/ethnic characterization in the sample

Our dataset included 13,609 White students (defined as students of European or Middle Eastern descent), 1032 Black or African American students, 488 Latin* students, 366 Asian students (including east, south, and southeast Asia), and 105 Native American students. We removed international students (109 individuals) from the sample because they face different challenges than domestic students from underrepresented groups. We also removed students who did not indicate their race on their applications (225 students). For the statistical power required for our quantitative analyses, we further aggregated race into a binary variable: persons excluded due to their ethnicity or race (PEER) and White and Asian students (non-PEERs). This places substantial limitations on our analyses and dismisses the possibility of examining the unique challenges of students from different ethnic/racial groups in the United States. As an example, the university studied here did not admit Black or African American students until 1964—10 years after school segregation was declared unconstitutional. The impact of this racist legacy on Black students today should not be underestimated. Our focus for this article, however, is on common existing structural barriers that discourage or hinder access to STEM degree programs for PEER students. For example, PEER students tend to come from under-resourced school districts in the United States and thus do not typically have the same educational opportunities as their White and Asian classmates prior to college (Reardon, 2013). This is the modern-day legacy of policies like segregation and redlining that continue to leave PEER students unprepared for the college academic environment. Here, we examine how common structural problems for PEER students unfold as barriers in their higher education STEM pathways. Finally, we note that Asian students may face discrimination and other barriers in secondary and postsecondary education that White students do not face. However, Asian students at this institution are more likely to graduate with a STEM degree than their White counterparts. 47% of Asian students with 95% CI = [0.42, 0.52] compared to 32% of White students with 95% CI = [0.31, 0.32] attain STEM degrees.

In our sample, we observed significant disparities in STEM degree attainment on the basis of marginalized identities with respect to student gender, race/ethnicity, and generational status (Fig. 2). Gender disparity: We found that men were about 30% more likely to graduate with a STEM degree (36% for men with 95% CI = [0.35, 0.37] compared to 27% for women with 95% CI = [0.26, 0.28]).

First generation characterization in the sample

In our sample, there were 1513 first generation (FG) college students and 13,654 students whose parent(s) attended college (continuing generation, or CG). There were 433 students for whom this information was not available and they were removed from analyses exploring STEM degree attainment in FG versus CG students.

Performance characterization in the sample

Our work focuses on performance outcomes of students, specifically test scores and grade point averages. However, we do not intend to suggest that the way in which students are assessed in our study allows for students to fully express their intellectual talents or reflects some ‘ideal’ approach to evaluating student knowledge. In fact, defining performance in terms of how it has historically been measured in higher education implies all students should behave like White men from high socioeconomic backgrounds (Eccles, 1994). Nonetheless, while acknowledging this flaw, it is still informative to examine student performance outcomes because they have real-world consequences for students, often dictating their educational and occupational trajectories. It is important to bear in mind, however, that these measures favor a privileged subset of students. Our institutional enrollment data included two measures of early academic performance: students’ composite ACT scores and their GPA in the first year enrolled at the university. The ACT is one of two widely used college entrance examinations in the United States and purports to measure high school academic preparation. It covers math, science, reading, and writing, and is scored out of 36 points. The interquartile range of composite ACT scores at this institution is 25–31, and the admissions rate at this institution was roughly 80% during the time period measurements were collected. Our institutional database only kept composite ACT scores and not math ACT scores. GPA in the United States is measured on a 4.0 scale, with 0 being the lowest grade and 4.0 being the highest grade. The median first year GPA at this institution is 3.13. We were missing these metrics from 862 students, who were removed from the structural equation models (see below).

Analysis

We used logistic regression to examine the extent of demographic disparities in STEM degree attainment across gender, race/ethnicity, and college generation. Logistic regression assumes a model of the form:

$$\log\left(\frac{P}{1-P}\right) = \beta_0 + \beta_1 \,\text{Demographic status},$$

where P is the probability of the outcome studied (in this case, graduating with a STEM degree), and Demographic Status is a binary variable for demographic status (i.e., gender, race/ethnicity, and college generation). We ran logistic regression analyses for each demographic variable of gender, PEER status, and first generation status separately. In our results, when we report the fraction of students in each demographic group who receive a STEM degree, we are reporting P. The error bars on measurements of P are computed using the emmeans package in R (Lenth, 2018).

To explore the underlying opportunity gaps that create observed demographic disparities in STEM degree attainment, we used structural equation modeling (SEM) with the lavaan package in R (Rosseel, 2012). SEM explores chains of relationships between variables (Ballen & Salehi, 2021). In this study, we employ SEM to explore which variables explain variance in STEM degree attainment among demographic groups (example in Fig. 1). In our models, a demographic gap in STEM degree attainment is illustrated by a significant direct link between demographics and STEM degree attainment. If this path is fully or partially mediated (explained) by another variable (the mediator), the direct link between demographics and STEM degree attainment will either no longer be significant or decrease in size when including the mediation path (path from demographic variables to mediator to STEM degree). Instead, the links between demographics and the mediator as well as the mediator and STEM degree attainment will be significant. In this paper, we investigate two primary mediators: intent to major in STEM and academic challenges during the first year of college. We also examine how each of these mediators are impacted by STEM high school preparation.

Different patterns of relationships among the variables in our models support different hypotheses:

Hypothesis 1 (aspiration disparities) Data to support this hypothesis would manifest in our analysis as a significant link between demographics and STEM degree attainment mediated by students' initial intention to major in STEM.

Hypothesis 2 (aspiration disparities caused by gaps in pre-college education) Data to support this hypothesis would manifest in our analysis as a significant link between demographics and intent to major in STEM mediated by a measure of high school preparation, American College Testing (ACT) entrance exam scores. Note that we only tested Hypothesis 2 for demographic groups with aspiration disparities as measured in Hypothesis 1.

Hypothesis 3 (attrition disparities caused by disproportionate academic challenges in the first year) Data to support this hypothesis would manifest in our analysis as a significant link between demographics and STEM degree attainment mediated by a measure of academic performance during the first year of college, students' first year GPA. One concern with this model is that students who major in STEM often have lower first year GPAs compared to students who do not major in STEM (due to the difficulty of STEM courses; Koester et al., 2016). However, in our data set, STEM majors' first year GPAs were not substantially different from non-STEM majors' GPAs—they differed by 0.03 grade points.

Hypothesis 4 (attrition disparities caused by gaps in pre-college education) Data to support this hypothesis would manifest in our analysis as a link between demographics and performance in early college (first year GPA) mediated by a measure of high school preparation (ACT exam scores). Again, we only tested hypothesis 4 for demographic groups in which introductory college courses accounted for attrition disparities as measured in Hypothesis 4.

In our models, pathways leading to continuous variables (e.g., first year GPA) represent correlation coefficients or differences by demographic group, depending on whether the predictor variable is continuous or binary. Pathways leading to binary variables (e.g., STEM degree attainment) represent odds ratios ($P/(1 - P)$ in the model above). To help with the interpretation of coefficients, we mean–variance standardized all continuous variables across the whole sample and coded binary demographic variables with the historically marginalized group as 1 and the majority group as 0. As examples of how to interpret the model coefficients, a positive coefficient between first year GPA and STEM degree attainment indicates how a standard deviation increase in first

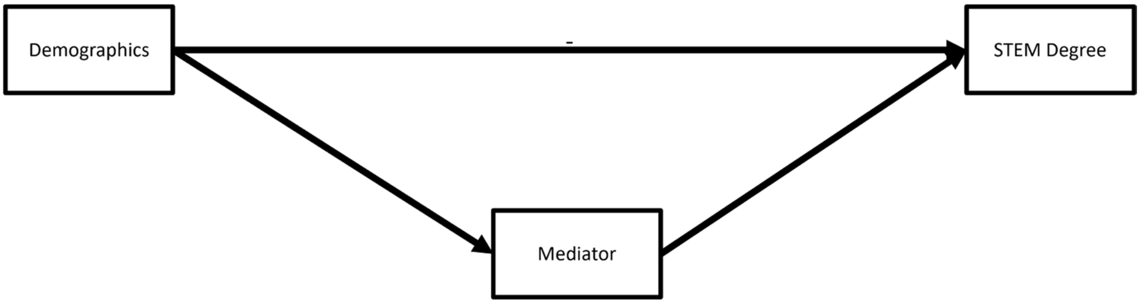

Fig. 1 Example structural equation model (SEM) illustrating how a third variable might mediate demographic disparities in STEM degree attainment. A demographic disparity in STEM degree attainment is captured by the link between demographic status and STEM degree attainment in these SEM figures

year GPA increases the odds of receiving a STEM degree, and a coefficient between gender (woman = 1) and STEM degree attainment that is smaller than one indicates an unfavorable odds ratio of women receiving STEM degrees compared to men.

Our models are completely specified (include all possible paths between variables). We included the direct link between demographics and STEM degree attainment in all models to account for the possibility that our models may not fully explain the disparities in STEM degree attainment. Because standard model fit statistics are not useful for completely specified models (Ballen & Salehi, 2021), we rely on the significance of the coefficients in the model to indicate whether a residual demographic disparity in degree attainment exists after controlling for intent to pursue STEM and/or performance in early coursework. In our models, we always included the direct link between demographics and STEM degree attainment to account for the possibility that gaps in STEM aspiration or attrition were not entirely explained by the mediators.

Results

In our sample, we observed significant disparities in STEM degree attainment on the basis of marginalized identities with respect to student gender, race/ethnicity, and generational status (Fig. 2). Gender disparity: We found that men were about 30% more likely to graduate with a STEM degree (36% for men with 95% CI = [0.35, 0.37] compared to 27% for women with 95% CI = [0.26, 0.28]). Racial and ethnic disparity: Similarly, non-PEER students were about 30% more likely to receive a STEM degree compared to PEER students (32% for non-PEER students with 95% CI = [0.31, 0.33] compared to 25% for PEER students with 95% CI = [0.23, 0.28]). Generational disparity: While smaller than the other two disparities, there also existed a generational disparity in attaining a STEM degree. Continuing generation students were about 15% more likely than first generation students to attain a STEM degree (32% for CG students with 95% CI = [0.31, 0.33] compared to 28% for FG students with 95% CI = [0.26, 0.30]).

In addition to the demographic disparities in degree attainment, we examined the demographic disparities in STEM pathways (Fig. 3). Gender disparity: As captured in the following Alluvial plot, women in our sample were less likely to earn STEM degrees but they were more likely to earn college degrees than men overall. The numbers of women changing from STEM to non-STEM majors after 1 semester of college and between years 2 and 6 are approximately equal, as indicated by the orange band leaving the green bars across genders, more than half of students leaving college with no degree left after the first year. Racial and ethnic disparity: PEER students who left STEM were more likely than non-PEERs to leave college with no degree instead of switching majors (Fig. 3, as indicated by the larger proportion of students in purple). A significant portion of PEER students departed sometime after the third semester. Generational disparity: The trend for FG students was similar to PEER students. An FG student who left STEM was more likely to leave college with no degree rather than change to a non-STEM major compared to a CG student. A significant fraction of FG students departed after the third semester.

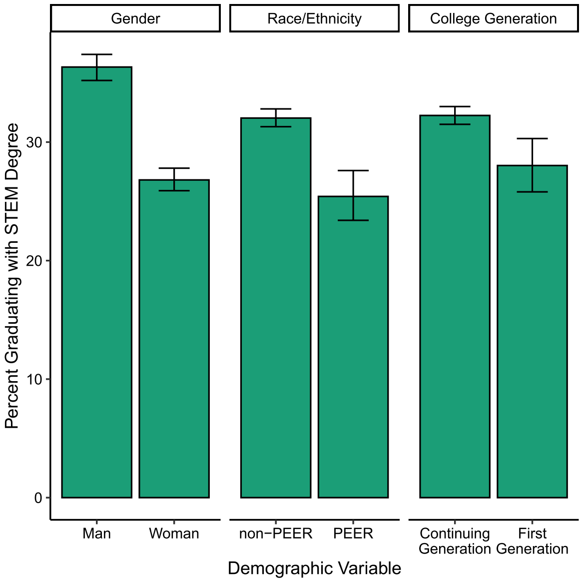

Fig. 2 Percent of students graduating with a STEM degree as a function of demographic variables. For each demographic variable, the difference between the two bars depicts disparities in STEM degree attainments between the majority and marginalized group, i.e., men and women (*N* = 15,600), non-PEER and PEER students (*N* = 15,600), and continuing generation and first generation students (*N* = 15,167). Error bars are 95% confidence intervals

In the following, we further explore the potential underlying causes for these demographic disparities in STEM pathways and degree attainment. Before explaining each result, we reiterate our hypothesis and then summarize our main findings in regard to that hypothesis.

Hypothesis 1 (aspiration disparities) College students from marginalized demographic groups are less likely to receive undergraduate STEM degrees because these students enter college with a lower intent to pursue a STEM degree.

We found that intent to major in STEM fully mediated the link between gender and STEM degree attainment (the aspiration gap by gender). Women were only 0.54 times as likely as men to intend to major in

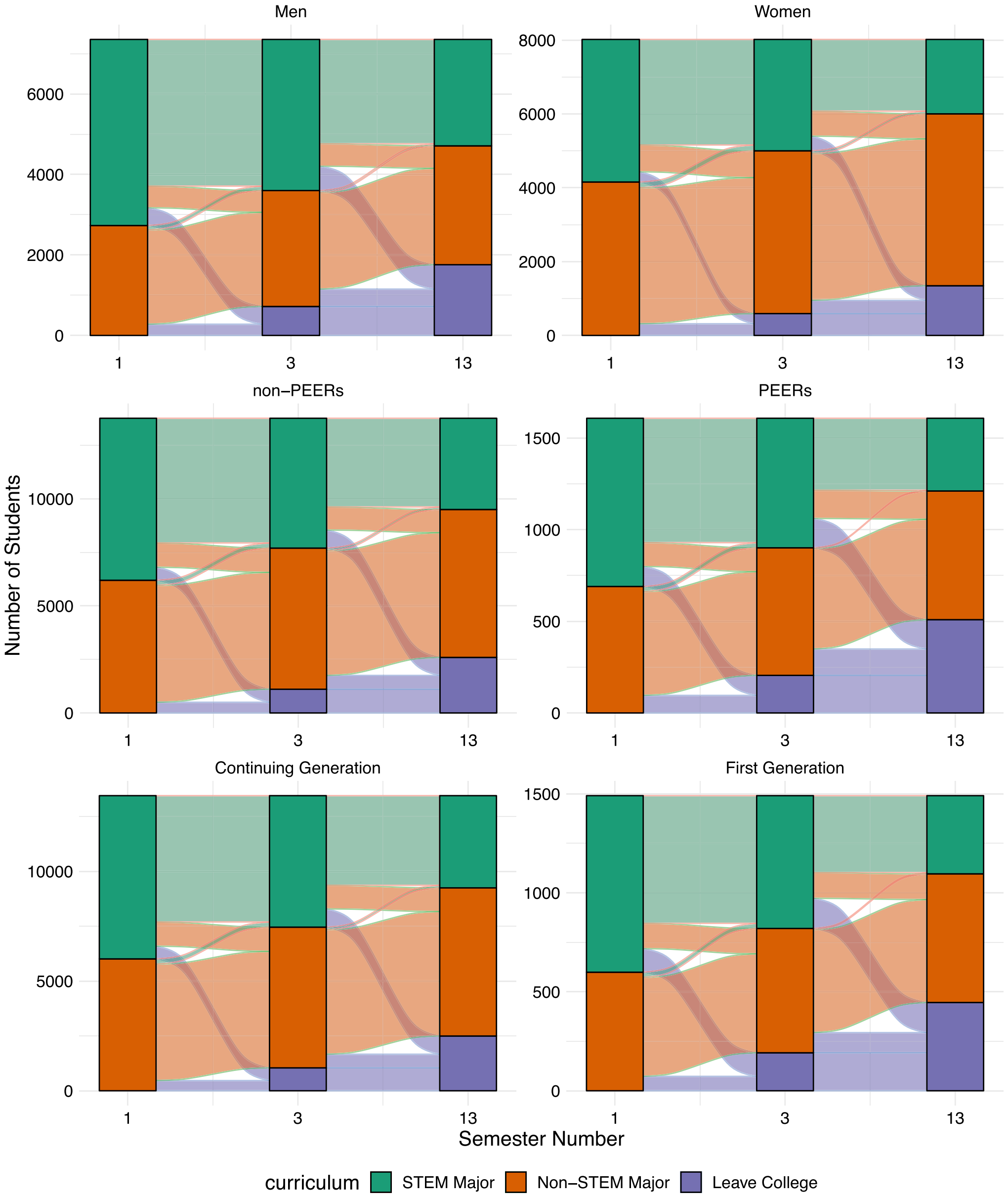

Fig. 3 Alluvial plots indicating students' initial majors (semester 1), and pathways into and out of STEM or college over 6 years (concluding after semester 12) among students: men and women (top), PEER and non-PEER (middle), and first generation and continuing generation (bottom). Green indicates that a student is in a STEM program, orange indicates that they are in a non-STEM program, and purple indicates that they have left college

STEM ($p < 0.001$), and students initially intending to major in STEM were 3.93 times more likely to graduate with a STEM degree ($p < 0.001$) (Fig. 4). Controlling for this mediation path, the direct link between gender and degree attainment was not statistically significant ($p = 0.13$).

Intent to major in STEM did not mediate the racial/ethnic disparities in STEM degree attainment. We found that PEER students were 1.2 times more likely than their non-PEER counterparts to intend to major in STEM ($p < 0.001$), and students who start in STEM were 3.96 times more likely to graduate with a STEM degree ($p < 0.001$) (Fig. 5). However, controlling for the mediating effect of intention to pursue STEM, PEERs were 0.67 times as likely to graduate with a STEM degree as their non-PEER counterparts who intended to pursue STEM degrees ($p < 0.001$). Thus, intent to major in STEM did not explain the racial/ethnic disparity in STEM degree attainment. Although PEER students started with higher intention to pursue STEM than their non-PEER counterparts, PEER students were still less likely to graduate with a STEM degree.

Similar to PEER students, we found that FG students were 1.23 times more likely to intend to major in STEM than their continuing generation counterparts ($p < 0.001$), and students who had initial STEM intentions were 3.95 times more likely to graduate with a STEM degree ($p < 0.001$) (Fig. 6). However, controlling for the mediating effect of intent to major in STEM, first generation students were only 0.71 times as likely as continuing generation students to graduate with a STEM degree ($p < 0.001$). Intent to major in STEM did not explain the generational disparity in STEM degree attainment. FG students started with higher intent to pursue STEM, but were less likely to attain a STEM degree compared to CG students.

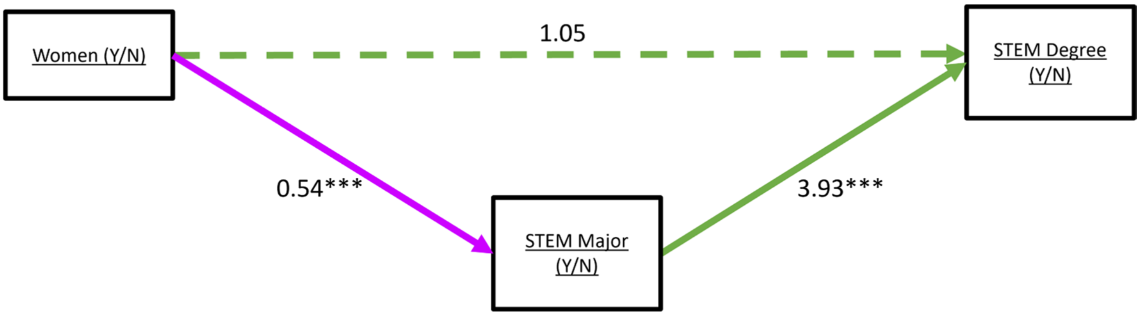

Fig. 4 SEM model of Hypothesis 1 indicating how initial intent to major in STEM mediates gender gaps in STEM degree attainment ($N = 14{,}738$). Dashed lines indicate nonsignificant links and solid lines indicate significant links (***p < 0.001). Because all variables are binary, green lines indicate an outcome is more likely, while magenta lines indicate an outcome is less likely

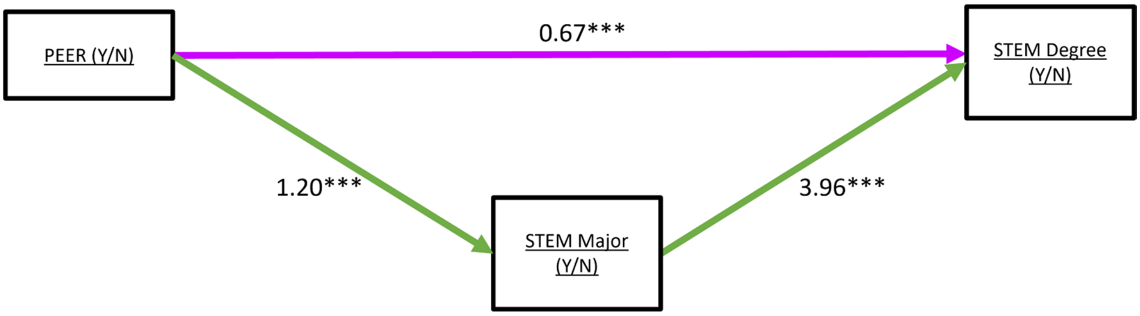

Fig. 5 SEM model of Hypothesis 1 indicating how initial intent to major in STEM mediates racial/ethnic gaps in STEM degree attainment ($N = 14{,}738$). All links are significant (***$p < 0.001$) and represent odds ratios. Because all variables are binary, green lines indicate an outcome is more likely, while magenta lines indicate an outcome is less likely

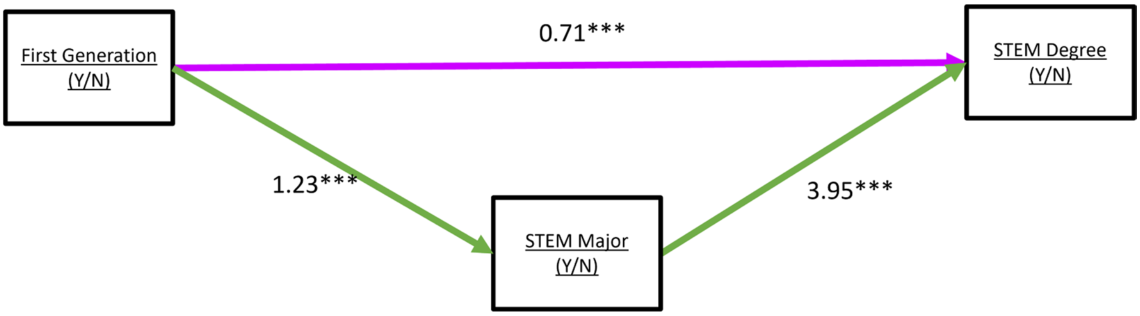

Fig. 6 SEM model of Hypothesis 1 indicating how initial intent to major in STEM mediates parental education gaps in STEM degree attainment ($N = 14{,}517$). All links are significant (***$p < 0.001$) and represent odds ratios. Because all variables are binary, green lines indicate an outcome is more likely, while magenta lines indicate an outcome is less likely

Overall, our analyses suggest that an aspiration gap exists across gender (women enter college with lower intention to pursue STEM) but not across race/ethnicity or generation status. In fact, PEER and FG students entered college with higher aspiration to pursue STEM degrees compared to their non-PEER and CG peers. However, despite this higher aspiration, they were less likely to attain a STEM degree and more likely to leave college without a degree.

We next explored whether the aspiration gap across gender was explained by differences in students' high school preparation, measured by ACT scores. That is, did high school opportunity gaps explain women's lower intent to major in STEM?

Hypothesis 2 (aspiration disparities caused by gaps in pre-college education) College students from marginalized demographic groups are less likely to receive undergraduate STEM degrees because of gaps in high school preparation, which in turn leads to gaps in their intention to pursue a STEM degree.

We found that women's ACT scores were 0.92 standard deviations lower than men ($p < 0.001$) (Fig. 7). High ACT scores increased students' intention to pursue STEM majors ($p < 0.001$) and receive a STEM degree ($p < 0.001$) (Fig. 7). Even controlling for women students' lower ACT scores, we still found that women were only 0.60 times as likely as men to select a STEM major. Without controlling for ACT scores, they were 0.54 times as likely to major in STEM (Fig. 4), indicating that women students' lower ACT scores did not significantly alter the gender gap in selecting a STEM major. We conclude that women's lower ACT score did not significantly contribute to women's lower intent to pursue STEM.

Hypothesis 3 (attrition disparities caused by disproportionate academic challenges in the first year) College students from marginalized demographic groups are less likely to receive undergraduate STEM degrees due to opportunity gaps in introductory 'weed out' courses that impose disproportionate academic challenges to marginalized students.

Women had first year GPAs that were 0.24 ($p < 0.001$) standard deviations higher than men, and each standard deviation increase in GPA increased the odds of obtaining a STEM degree by a factor of 2.65 ($p < 0.001$) (Fig. 8). This pathway suggests that women obtain more STEM degrees than men. However, controlling for the mediating effect of first year GPA, women were only 0.49 times as likely as men to graduate with STEM degrees ($p < 0.001$) (Fig. 8). These results show that women were not less likely to pursue STEM because they faced more academic challenges during the first year of college. Instead, other factors, such as intent to major in STEM (Hypothesis 1), contributed to the gender disparity in STEM degree attainment.

PEER students' first year GPAs were 0.31 standard deviations lower than their non-PEER counterparts ($p < 0.001$), and each standard deviation increase in first year GPA made students 2.46 times more likely to graduate with a STEM degree ($p < 0.001$) (Fig. 9). Controlling for first year GPA, PEER students were equally likely as non-PEER students to receive a STEM degree, suggesting that academic difficulty during the first year of college

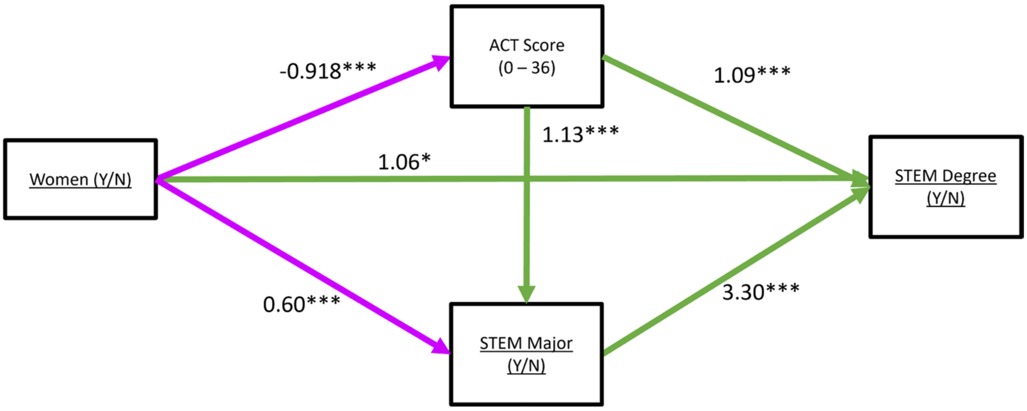

Fig. 7 SEM model of Hypothesis 2 indicating how prior preparation and initial intent to major in STEM mediate gender gaps in STEM degree attainment ($N = 14{,}738$). A pathway testing whether intent is mediated by prior preparation is also included. Solid lines indicate significant links (*$p < 0.05$, ***$p < 0.001$). Green lines leading to binary variables indicate an outcome is more likely, while magenta lines leading to binary variables indicate an outcome is less likely. Magenta lines leading to continuous variables mean indicate a negative correlation

was the main mediator for racial/ethnic disparities in STEM degree attainment.

FG students' first year GPAs were 0.20 standard deviations lower than their CG counterparts ($p < 0.001$), and each standard deviation increase in GPA made one 2.45 times more likely to receive a STEM degree ($p < 0.001$) (Fig. 10). When controlling for first year GPA, FG students were equally likely as their CG counterparts to receive a STEM degree. Therefore, similarly to the case for PEER students, academic difficulty during the first year of college was a main factor contributing to the generational disparity in STEM degree attainment.

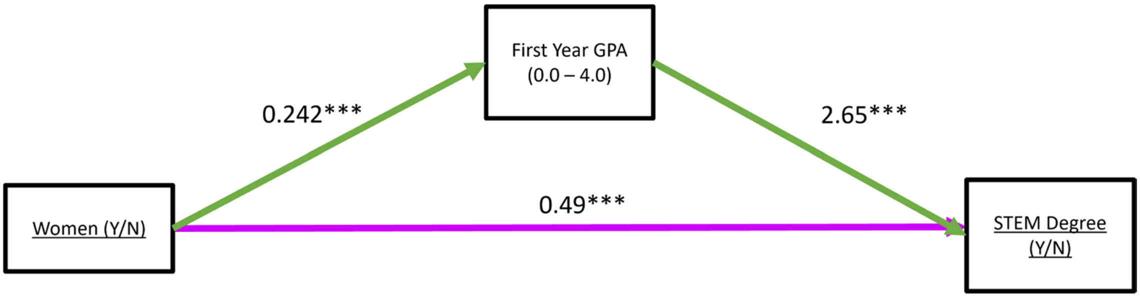

Fig. 8 SEM model of Hypothesis 3 indicating how first year GPA mediates gender gaps in STEM degree attainment ($N = 14{,}738$). Solid lines indicate significant links (***$p < 0.001$). Green lines leading to binary variables indicate an outcome is more likely, while magenta lines leading to binary variables indicate an outcome is less likely. Magenta lines leading to continuous variables mean indicate a negative correlation, while green lines leading to continuous variables indicate a positive correlation

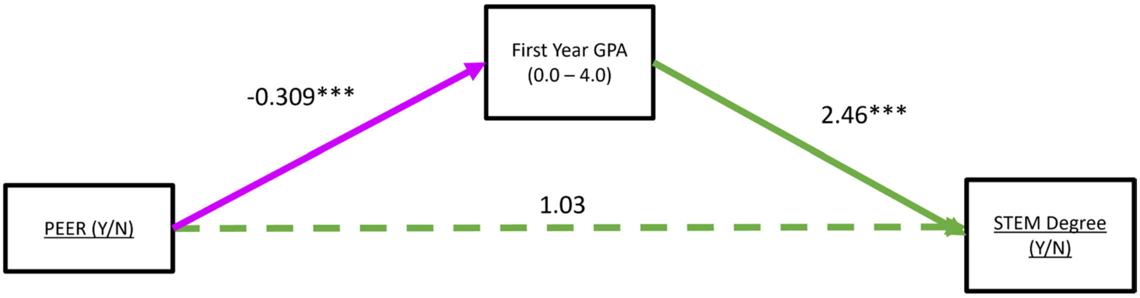

Fig. 9 SEM model of Hypothesis 3 indicating how first year GPA mediates racial/ethnic gaps in STEM degree attainment ($N = 14{,}738$). Solid lines indicate significant links (***$p < 0.001$) and dashed lines indicate nonsignificant links ($p > 0.05$). Green lines leading to binary variables indicate an outcome is more likely, while magenta lines leading to binary variables indicate an outcome is less likely. Magenta lines leading to continuous variables mean indicate a negative correlation, while green lines leading to continuous variables indicate a positive correlation

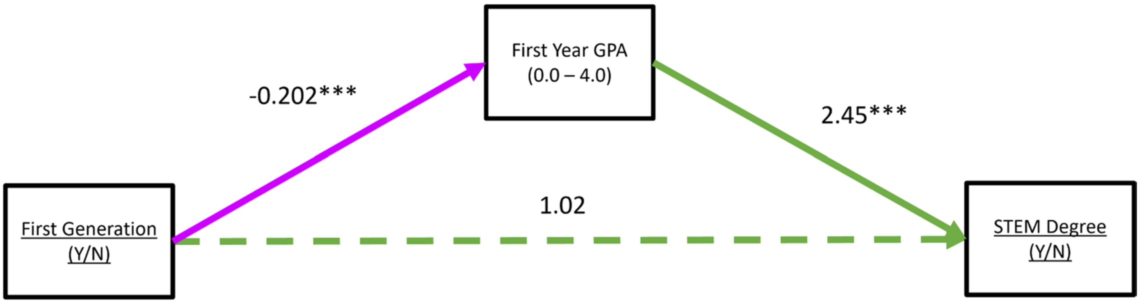

Fig. 10 SEM model of Hypothesis 3 indicating how first year GPA mediates parental education gaps in STEM degree attainment ($N = 14{,}517$). Solid lines indicate significant links (***$p < 0.001$) and dashed lines indicate nonsignificant links ($p > 0.05$). Green lines leading to binary variables indicate an outcome is more likely, while magenta lines leading to binary variables indicate an outcome is less likely. Magenta lines leading to continuous variables mean indicate a negative correlation, while green lines leading to continuous variables indicate a positive correlation

We further explored whether the attrition disparities across race/ethnicity and college generation resulted from opportunity gaps in high school preparation, measured by ACT scores.

Hypothesis 4 (attrition disparities caused by gaps in pre-college education) College students from marginalized demographic groups are less likely to receive undergraduate STEM degrees because of inadequate high school preparation, leading to disproportionate academic challenges in early undergraduate courses.

We found that PEER students' ACT scores were 2.15 standard deviations lower than non-PEER students ($p < 0.001$) (Fig. 11). This is a sizable difference, corresponding to roughly 6 points in actual score (out of 36). Each standard deviation increase in ACT score translated to a 0.09 standard deviation increase in first year GPA ($p < 0.001$) (Fig. 11). However, controlling for ACT scores, a 0.13 standard deviation gap still existed between PEER and non-PEER students in first year GPA ($p < 0.001$) (Fig. 11). Without controlling for ACT scores, PEER students' first year GPAs were 0.31 stand deviations lower than non-PEER students' GPA (Fig. 9). 60% of the gap in first year GPAs was explained by PEER students' lower ACT scores; this was calculated by comparing the link between GPA and PEER status in Figs. 11 vs. 9. Without the mediating factor of ACT score, the link was 0.31 standard deviations, and with the link it drops to 0.13 standard deviations. In Hypothesis 3, first-year GPA was the only mediator for STEM degree attainment of PEER students. Here, it remains the primary mediator, with each standard deviation increase in first year GPA being correlated with a 1.93 times higher odds of receiving a STEM degree. This is smaller than the 2.46 odds ratio seen previously, indicating that a small percentage of STEM degree attainment disparities are explained by high school preparation separately from its mediation effect on first-year GPA.

FG students' ACT scores were 0.85 standard deviations lower than their CG counterparts ($p < 0.001$) (Fig. 12). Each standard deviation increase in ACT score corresponded to a 0.09 standard deviation increase in first year GPA ($p < 0.001$) (Fig. 12). There was still a 0.13 standard deviation gap in first year GPA when controlling for ACT scores ($p < 0.001$) (Fig. 12). Without controlling for ACT scores, a 0.20 standard deviation gap in first year GPA existed (Fig. 10). Comparing the coefficients in models with and without ACT scores as mediating pathways indicates that 40% of the gap in first year GPA for FG students was explained by incoming academic preparation. In Hypothesis 3, first-year GPA was the only mediator for STEM degree attainment of FG students. Here, it remains the primary mediator, with each standard deviation increase in first year GPA being correlated with a 1.94 times higher odds of receiving a STEM degree. This is smaller than the 2.45 odds ratio seen previously, indicating that a small percentage of STEM degree attainment disparities are explained by high school preparation separately from its mediation effect on first-year GPA. The nonsignificant link between FG and STEM degree indicates that high school preparation and first-year performance combined explain the gap in STEM degree attainment.

In summary, we observed that women, marginalized racial/ethnic students, and first generation students were

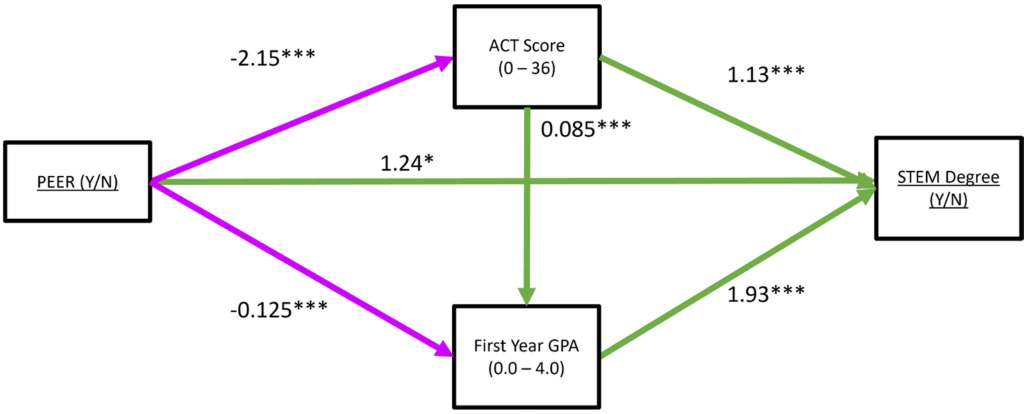

Fig. 11 SEM model of Hypothesis 4 indicating how incoming preparation and first year GPA mediate racial/ethnic gaps in STEM degree attainment ($N = 14{,}738$). We also include a link showing how incoming preparation mediates gaps in first year GPA. Solid lines indicate significant links (*$p < 0.05$, ***$p < 0.001$). Green lines leading to binary variables indicate an outcome is more likely, while magenta lines leading to binary variables indicate an outcome is less likely. Magenta lines leading to continuous variables mean indicate a negative correlation, while green lines leading to continuous variables indicate a positive correlation

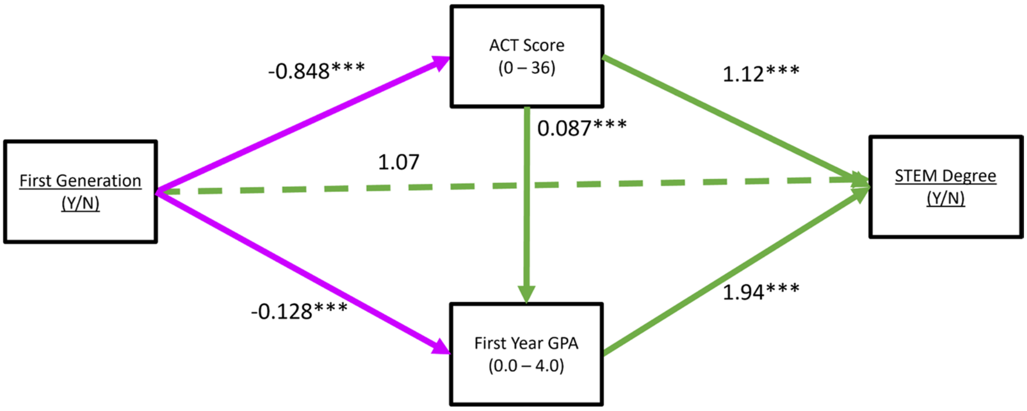

Fig. 12 SEM model of Hypothesis 4 indicating how prior preparation and first year GPA mediate generational gaps in STEM degree attainment ($N = 14{,}517$). We also include a link showing how prior preparation mediates gaps in first year GPA. Solid lines indicate significant links (*$p < 0.05$, ***$p < 0.001$) and dashed lines indicate nonsignificant links ($p > 0.05$). Green lines leading to binary variables indicate an outcome is more likely, while magenta lines leading to binary variables indicate an outcome is less likely. Magenta lines leading to continuous variables mean indicate a negative correlation, while green lines leading to continuous variables indicate a positive correlation

all less likely than their majority peers to graduate with a STEM degree (Demographics Only models in Fig. 13). The underlying mechanisms that created opportunity gaps were different for these three groups. For women, the gendered disparity in STEM graduation rates was mainly explained by a gendered aspiration gap with women starting college with lower intention to pursue a STEM major, evidenced by the disappearance of the gender disparity in STEM graduation when controlling for the intent to major in STEM (Demographics + Intent to Major in STEM model for Gender in Fig. 13). However, an aspiration gap was not related to racial/ethnic and generation disparities in STEM graduation rates. In fact, FG and PEER students started college with higher intention to pursue STEM than their counterparts. For these two groups, the likely cause of STEM graduation disparities was an attrition gap. These students faced disproportionate academic challenges during college and therefore left STEM at a higher rate compared to their majority peers, evidenced by no racial/ethnic and generational disparity in STEM graduation rates when controlling for first year GPA (Demographics + First Year GPA for Race/Ethnicity and College Generation in Fig. 13).

Discussion

In alignment with national trends (Trapani & Hale, 2022), we found women, PEERs, and first generation college students were less likely to receive a STEM degree compared to men, White and Asian students, and continuing generation students at a large, research-intensive university. In this work, we use an opportunity gap framework to further unpack the systemic mechanisms leading to demographic disparities and aim to recommend interventions that can effectively address opportunity gaps. Our results underscore that the mechanisms explaining demographic disparities in STEM degree attainment varied widely across demographic groups. The results reveal two different mechanisms that explain demographic disparities in STEM degree attainment: gender disparities in aspiration to study STEM when entering college versus racial/ethnic and college generation disparities in attrition during college. The lower likelihood of receiving an undergraduate STEM degree among women was associated with high school and primary educations that did not equally seed aspiration to pursue STEM in women and men. Unlike women, PEER and FG students were more likely to intend to major in STEM than their non-PEER and CG counterparts. However, they were still less likely to receive an undergraduate STEM degree due to higher rates of attrition during college. Here, we observe the higher education system failed to equally support all students in pursuing STEM pathways. PEER and FG students were faced with disproportionate academic challenges and were awarded lower scores in introductory courses, and hence they were more likely to leave STEM pathways and/or college altogether.

Lower intent to major in STEM among women entering university was associated with differential STEM degree attainment between men and women. This result points towards the long-lasting impact of structural inequities that occur before university in shaping gender gaps in STEM degree attainment. Importantly, our data best support the model that is unrelated to incoming academic preparation—that is, girls and women do not choose STEM for reasons unrelated to the quality of their pre-college education. In fact, we show academic

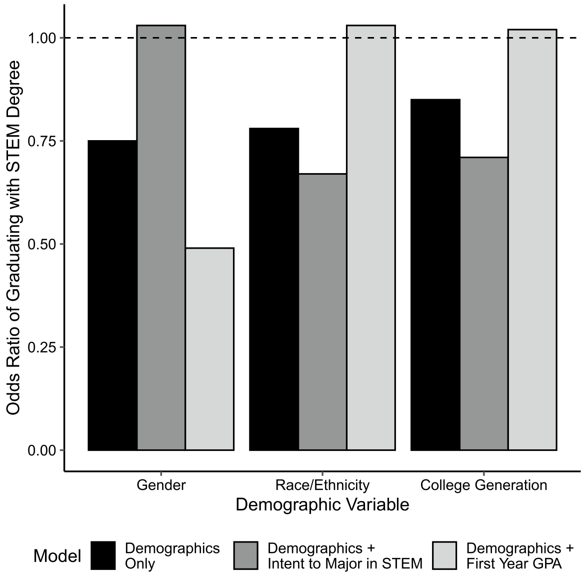

Fig. 13 The odds of graduating with a STEM degree for a marginalized group compared to a majority group (women compared to men, PEER compared to non-PEER, and first generation compared to continuing generation). Odds ratios were calculated without controlling for other variables (Demographics Only model; black bars), while controlling for intent to major in STEM (Demographics + Intent to Major in STEM model; dark grey), and while controlling for first year GPA (Demographics + First Year GPA model; light grey). The dashed line indicates an odds ratio of one for which the likelihood of graduating with a STEM degree is equal between marginalized and majority groups. This figure illustrates the odds of graduating with a STEM degree are lower among the marginalized groups but become equal when controlling for different factors: for women, the odds of graduating with a STEM degree are the same as men when controlling for the intent to major in STEM (Hypothesis 1); for marginalized race/ethnicities and first generation students, the odds of graduating with a STEM degree are the same as majority race/ethnicities and continuing generation students when controlling for first year GPA (Hypothesis 3)

preparation did not significantly change the gender gap in degree attainment. This means other factors that do not relate to academic preparation are important. Many factors, ranging from microaggressions to outright discrimination to gender role socialization (Aycock et al., 2019; Barthelemy et al., 2016; Harrison & Tanner, 2018; Marín-Spiotta et al., 2020), undoubtedly contribute to gendered patterns of educational and occupational outcomes. For example, subtle or overt messaging discourage women from engaging in STEM fields during childhood and adolescence (Sjaastad, 2012; VanMeter Adams et al., 2014). Additionally, stereotypes of scientists emerge as early as six years old and shape children's perceptions of who can be a scientist (Bian et al., 2017; Chambers, 1983). This is partly due to the absence of women role models in curricular materials (Kerkhoven et al., 2016; Wood et al., 2020) and in the mass media (Kitzinger et al., 2008; Witt, 2000). Information provided by parents, teachers, and school counselors can also influence student perceptions of their future in STEM (Eccles et al., 2000; Falco, 2017; Ikonen et al., 2017). Finally, the portrayal of science as stable, rigid, and lacking personal connection with the world or daily lives of students disproportionately discourages women and girls (Holmegaard et al., 2014). Future work that analyzes the positive impacts of role models and effective forms of encouragement will clarify the role that early societal messaging plays in women's and girls' intent to pursue STEM.

PEER and FG students were less likely to receive a STEM degree compared to their non-PEER and CG counterparts, despite strong intent to major in STEM in both groups. This disparity was explained by performance gaps faced during the first year of college. As most students intending to major in STEM take introductory STEM courses during their first year of college, our results underscore how 'weed out' introductory STEM courses decrease diversity in STEM majors (Mervis, 2011). After the first year, our descriptive statistics showed FG and PEER STEM students were more likely to leave the university with no degree rather than change to a non-STEM major (Fig. 3). In line with prior literature (Hazari et al., 2007; Salehi et al., 2019), these performance gaps between PEER and FG students and their counterparts during the first year of college were largely seeded by disparities in access to high quality education prior to college. Educational opportunity gaps exist, as students with low socioeconomic status and minoritized identities attend under-resourced schools beginning in preschool and persisting through high school (Carter & Welner, 2013). As a direct result of these pre-college opportunity gaps, we found that high school preparation explained 60% of the PEER gap and 40% of the FG gap in academic performance during the first year of college. The remaining performance gap not accounted for by high school STEM preparation may be due to the fact that we have a crude and biased measure for STEM high school preparation (ACT composite) (Bettinger et al., 2013). Additionally, following an opportunity gap framework, we emphasize the potential failures of the institutional context as an important factor that has implications for STEM pathways and degree attainment among marginalized groups. As the institution under study has a primarily White, continuing-education student population, our results may be driven by exclusionary learning environments and dominant discourse that negatively impact students with minoritized identities. For example, challenges faced by PEER and FG students during college can include exclusionary learning environments or chilly classroom climates (Rainey et al., 2019), few role models in curricular materials (Becker & Nilsson, 2022; Wood et al., 2020), and experiences of microaggressions and/or discrimination on the basis of identity factors (Harrison & Tanner, 2018; Lee et al., 2020; Salehi et al., 2021). We draw these examples from existing literature, rather than the institution under study in the current research and recognize that further qualitative data are needed to gain insights into students' lived experiences in this context.

The location along the STEM pathway where disparities occur has implications for the effectiveness of interventions to promote equity in STEM education. Our results suggest that interventions aiming to increase the representation of women in STEM will be best focused on outreach programs and early exposure to women scientists, whereas interventions aiming to increase the representation of certain racial/ethnic groups will be most effective by focusing on addressing gaps in academic preparation for college and supporting these students during the first year experience. Many institutions employ STEM outreach programs to recruit diverse students and have first year programs designed to promote student success in STEM. Our results suggest that these STEM outreach programs will be most effective by focusing on recruiting girls and women to pursue STEM, as our gaps in STEM graduation among women were largely driven by gaps in their initial enrollment in STEM majors. Furthermore, our results suggest that first year programs that teach academic skills and STEM content are likely important vehicles for increasing representation of PEER and FG students in STEM (Estrada & Masui, 2019; Maton et al., 2000). The present study focuses on the impact of early academic performance and experience on attaining a STEM degree. However, approximately 50% of the students who leave STEM do so in the later years of college. This late exodus from STEM degrees highlights a general need for continuing academic and cocurricular support to ensure the success of all students in STEM programs.

Limitations

The results of this study are limited by the resolution of institutional datasets. Most institutions conflate records of gender and biological sex, thereby obscuring the experiences of transgender, nonbinary, genderqueer, and genderfluid students. Many openly transgender students drop out of school due to harassment based on their gender identity, and LGBT individuals who continue in STEM face harassment and career limitations within STEM professions (Cech & Waidzunas, 2021; Grant et al., 2011). We applaud efforts underway at this institution to collect continuous measures of gender identity and expression, as this information will allow for robust investigations into challenges faced by transgender, nonbinary, genderqueer, and genderfluid individuals in pursuing STEM degrees.

An additional limitation with our analysis is our reliance on composite ACT scores to measure high school academic preparation. As mentioned earlier, ACT scores provide a biased and inaccurate measure of student knowledge (Bettinger et al., 2013). Furthermore, composite ACT scores are not STEM-specific. Previous work has shown that STEM content-specific measures of incoming preparation such as concept inventories better capture gender disparities in STEM incoming preparation (Salehi et al., 2019). If our gender analyses included concept inventories instead of composite ACT scores, high school preparation would have likely mediated the gender gap in student intent to major in STEM to a larger extent, in line with the literature that clearly demonstrates that early exposure to STEM coursework (McGill et al., 2015; VanMeter-Adams et al., 2014) and achievement in STEM courses during high school (Maltese et al., 2014; Tai et al., 2006) promote interest in STEM for women. We also would likely have seen a stronger link between high school preparation measured with STEM inventories and struggle in the first year of college for FG and PEER students, as concept inventories may better reflect systemic inequities in secondary STEM education.

Another limitation to the present study is that we only analyzed data from a single institution. Future work will examine the relative impacts of aspiration and attrition on marginalized students at minority serving institutions, primarily undergraduate institutions, and other research-intensive universities. In our analysis of a single institution, we further aggregated all STEM disciplines into a monolithic construct, which may obscure differences in attrition and aspiration among different disciplines. Nationally, the demographic composition of STEM majors varies across disciplines with, for example, more women majoring in biology than in engineering (Trapani & Hale, 2022). Given that 45% of STEM students in this study entered college intending to major as engineers, our sample likely obscures the gender parity that exists in STEM disciplines such as biology. These demographic differences across disciplines reinforce the need to tailor interventions not only to demographic groups of interest but also to STEM disciplines of interest. Such efforts further underscore the importance of evidence-based approaches to promote diversity in STEM degree holders.

Conclusions

This work applies an opportunity gaps framework to examine the underlying mechanisms leading to demographic disparities in STEM degree holders and to identify locations along STEM pathways where opportunity gaps operate for different demographic groups. Harnessing large institutional datasets for this purpose helps us understand fundamental patterns responsible for observed demographic disparities and provides guiding insights for our national efforts to resolve them. The results presented here highlight that opportunity gaps vary for different marginalized demographic groups and operate at different points along STEM pathways. Our results therefore suggest that different interventions are required to support different student identities in their STEM pathways. We show that a gendered aspiration gap generated prior to college dictates gender disparities in STEM degree holders. We further show that gaps in high school STEM preparation are consequential for racial/ethnic and generational disparities in STEM graduates. Gaps in STEM preparation create disproportionate academic challenges for PEER and first generation students during their first year of college. Therefore, these students leave STEM pathways at higher rates compared to their majority peers despite the fact that they start college more likely to intend to pursue STEM. To promote equity in pathways for any STEM field, we need to better understand opportunity gaps specific to each marginalized demographic group as well as orchestrate these equity efforts both prior to and during college education.

Abbreviations

CG	Continuing generation, students with one or more parents who graduated from college
FG	First generation, students with parents who did not graduate from college
non-PEER	Persons not excluded from STEM because of their ethnicity and/or race, i.e., White and Asian students
PEER	Persons excluded because of their ethnicity and/or race
SEM	Structural equation modeling
STEM	Science, technology, engineering, and mathematics

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Author contributions

RAC analyzed the institutional data and created figures with support from SS and EB. All authors contributed to the writing of the manuscript and approved the final version of the manuscript.

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Availability of data and materials

The institutional dataset analyzed during the current study is not available per constraints from Auburn University IRB Protocol 21-573.

Declarations

Competing interests

The authors declare that they have no competing interests.

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