Journal for STEM Education Research
https://doi.org/10.1007/s41979-023-00107-8

RESEARCH ARTICLE

Undergraduate Research Experience and Post-graduate Achievement Among Students from Underrepresented Groups in STEM

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Accepted: 14 August 2023

Abstract

Racial and ethnic disparities in STEM achievement are associated with weaker economic growth, greater social inequalities, and narrower parameters of scientific inquiry. Extant research suggests that undergraduate research experiences (URE) can reduce those disparities by enhancing perceptions of belonging and scientific self-efficacy among students from underrepresented groups. However, to date, very few studies have examined the relationship between URE and *post-baccalaureate* educational achievement gains among such students and those that have tend to be limited in terms of causal leverage and generalizability. In this study, we aim to make progress by analyzing data from the California State University system's longstanding Louis Stokes Alliance for Minority Participation (CSU-LSAMP) program. Applying a quasi-experimental research design and drawing upon a large and representative sample of students whom we tracked over time, we observe that URE is strongly associated with post-baccalaureate enrollment and graduation in STEM disciplines among students from underrepresented backgrounds.

Keywords Research experience · Persistence · Underrepresented students · Graduate education

Only about half of all students who enroll in post-secondary education complete their course of studies and earn a degree (Dynarski, 2008). This is disconcerting and a real obstacle for various policy efforts to increase educational attainment. Therefore, it is not surprising that both policymakers and researchers are interested in finding ways to improve retention among college students. The problem of degree completion is especially acute in the fields of science, technology, engineering, and math (STEM). Indeed, a recent study found that 69% of students who declare a STEM major do not finish a STEM degree (Chen, 2013).

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Published online: 06 September 2023

The relatively low rate of retention among college students in STEM fields has been viewed with concern for a number of reasons. Some view this with foreboding, and a sense that the preeminence of the USA as the global leader in science and technology is waning (Coley & Vallas, 2015; President's Council of Advisors on Science and Technology, 2012). At the least, high stop-out rates in STEM fields cause to worry about explicit or implicit bias within the sciences that imposes real barriers to women and students from underrepresented and marginalized groups (Museus et al., 2011).

The large attrition rates could reflect inadequate preparation in high school (Villarejo & Barlow, 2007). Dickson (2010) finds that women are more likely to switch out of engineering majors, even after conditioning on high school coursework and grades. Furthermore, socio-economic status is related both to epistemic beliefs in science and science-related test scores in high school (Rozgonjuk et al., 2022). Another explanation for high levels of attrition from STEM programs is that students have difficulty seeing themselves as scientists, applying the concepts learned in class to scientific problems. This is an especially acute concern for women and students from underrepresented racial/ethnic backgrounds, where representation among university faculty is typically limited.

The problem of underrepresentation in the STEM fields after college is even more severe. A recent study of diversity in STEM fields by the National Science Foundation reports that just 5.6% of students enrolled in math, engineering, or computer science PhD programs in 2021 were Black (National Center for Science and Engineering Statistics, 2023). The same year, 8.8% of math and computer science PhD students identified as Hispanic or Latine. Even outside of PhD programs, just 14% of college educated workers in STEM fields are Black, Hispanic, or Latine, compared to more than 20% of college educated workers in other fields (National Center for Science and Engineering Statistics, 2023).

In this study, we evaluate the role of one potential solution that has received substantial attention for improving retention in STEM: undergraduate research experience (URE) outside the classroom. As we elaborate below, there are several mechanisms through which URE may boost persistence in STEM, particularly among students from underrepresented groups. These include increasing students' engagement and understanding of subject matter, inducing students to spend more time in preparation for class encounters, improving levels of communication and understanding between students and faculty, and improving perceptions of self-efficacy and belonging in STEM fields.

There is substantial evidence that URE heightens students' motivation and perceptions of scientific efficacy, their likelihood of attaining a baccalaureate degree, and their post-graduate educational aspirations (National Academies of Sciences, Engineering, and Medicine, 2017; Zubair & Al-Thani, 2022). However, extant scholarship lacks sufficient rigor to establish a link between URE and post-graduate enrollment, let alone completion, in STEM (Hurtado et al., 2014; National Academies of Sciences, Engineering, and Medicine, 2017; Pender et al., 2010). This is because previous studies have tended to focus on students' stated *intent* to obtain a post-graduate degree, which is a low-cost ambition to express among students in programs that are designed to enhance such ambitions. Indeed, there is good evidence that in other settings, differences in stated intent to enroll and actual matriculation in a degree program are substantial (Castleman & Page, 2014).

Several studies have found evidence that programs that encourage research experience among students increased the likelihood of obtaining admission to (Crawford et al., 1996; Haeger et al., 2020) or enrolling in graduate programs (e.g., Jones et al., 2010). Other studies, however, have illustrated that students who participated in URE were more likely to have expressed interest in graduate school even while in high school (Haeger et al., 2020; Hunter et al., 2007) and that participating in structured research experiences did not modify those plans (Lopatto, 2007). Research on the impact of URE on post-graduate STEM outcomes has been limited primarily to studies that retrospectively survey students/alumni (Lopatto, 2007; Russell et al., 2007) or focus on one university or program (Barlow & Villarejo, 2004; Maton et al., 2000). An important exception is the careful longitudinal analysis conducted by Hernandez et al., (2018), but it is somewhat limited with respect to sample size, and, more importantly, it does not measure actual post-graduate degree attainment in STEM as one of its outcome variables.

We aim to strengthen the breadth and validity of previous findings by analyzing data from the California State University (CSU) system's Louis Stokes Alliance for Minority Participation (CSU-LSAMP). The CSU-LSAMP program, which includes all 23 CSU campuses, is one of the largest and longest standing programs in the country aimed at boosting STEM persistence among students from underrepresented groups. It employs an array of strategies to do so, only one of which is providing URE. By holding LSAMP participation constant in our analyses, we mitigate the potentially confounding influence of other interventions.

Specifically, we draw upon a dataset of all CSU undergraduates who participated in LSAMP between 2004 and 2019 for whom we could also obtain information about them after graduation from both the National Student Clearinghouse and the CSU's Enrollment Reporting System (n=10,143), tracking their educational pursuits and achievements over time. These unique institutional data offer leverage in measuring post-graduate enrollment and graduation that survey reports of future intentions do not. We use a quasi-experimental design (propensity score matching with inverse probability weights) to account for a variety of potentially confounding influences at both the student level and institutional (campus) level.

We estimate that CSU-LSAMP program participants who engaged in organized research activities were markedly more likely than others to (1) obtain a STEM baccalaureate degree, (2) enroll in a post-secondary degree program, and (3) obtain a STEM post-graduate degree. We observe these patterns both among students who begin their college careers at a CSU and among those who transfer to a CSU from another college or university.

URE and Academic Achievement Among Students from Underrepresented Groups: Theory and Case Selection

Administrators and researchers in higher education have implemented and studied a wide number of interventions aimed at improving retention and boosting post-graduate enrollment in STEM, particularly among students from underrepresented (UR) groups. Among the most prominent of these is structured research experience under the guidance of a faculty member (e.g., Clewell et al., 2005). There are various mechanisms through which research experience as a supplement to coursework may enhance success and commitment to STEM which are thought to operate. These include enhancing the learning process (Lopatto, 2007), motivation, and engagement (Seymour & Hewitt, 1997) and enhancing confidence (Estrada et al., 2018; Hunter et al., 2007). Furthermore, the apprenticeship opportunity provided by research experience affords students the opportunity to participate in the community of science. Research experience, rather than passive learning in the classroom, can provide an active means of participation in the community of science and connect students to mentors (Hunter et al., 2007; Palid et al., 2023). Furthermore, as Hathaway et al., (2002) suggest, research experience may facilitate academic and social integration. These mechanisms echo Astin's (1999) theory of involvement: students who are involved in academic activities in college are more dedicated to their studies and more likely to persist.

A large body of literature suggests that such research experience boosts motivation, perceptions of scientific efficacy, and aspirations for graduate education (see for review: Pender et al., 2010). However, we have a limited understanding of the extent to which such research experience actually leads to greater post-graduate enrollment and achievement (Pender et al., 2010). To gain purchase over these questions, we examine student experiences and outcomes within the context of the National Science Foundation's Louis Stokes Alliance for Minority Participation (LSAMP). The LSAMP is an inter-university consortium across the USA that applies numerous interventions to encourage students to pursue post-graduate education in STEM (e.g., Gibson et al., 2021; Okojie et al., 2021).

Perhaps the most prominent LSAMP program is California State University's 23 campus "STEM Pathways and Research Alliance" Program (CSU-LSAMP). As the largest baccalaureate degree granting institution in the USA, the CSU is the primary destination for California's students enrolling in 4-year institutions. More than one-third of the CSU's entering first-years are first-generation college students, and the CSU system awards almost two-thirds (62%) of all bachelor's degrees to California's Hispanic students, almost half (47%) of all undergraduate degrees to African American students, and 43% of all undergraduate degrees to Native American students.[1] However, there is still a considerable achievement gap between students from UR and non-UR groups, particularly in STEM, within the CSU. For example, the 6-year graduation rate of non-UR students entering as first-years is 1.5 times higher than Hispanic students and about 2.5 times higher than African American students.[2]

Thus, the programmatic objectives of the CSU-LSAMP are to support students in achieving academic integration and a sense of belonging in their

[1] The California State University, *Impact of the CSU/Diversity*. Available at: https://www2.calstate.edu/impact-of-the-csu/diversity.

[2] *California State University Louis Stokes Alliance for Minority Participation STEM Pathways and Research Alliance, Year Two Report*, June 2020, Institute for Social Research. Available at: https://www.csus.edu/college/natural-sciences-mathematics/csu-lsamp/_internal/_documents/csu-lsamp-spara-year-two-report.pdf.

disciplines—including a strong sense of scientific identity. CSU strategies to achieve these objectives rely heavily on routine student interaction, campus-based resources, and activities, as well as in-person academic-related activities. Thus, the CSU-LSAMP program is explicitly designed around the students' connection to campus and in-person educational experiences. Because the CSU-LSAMP Alliance includes all 23 campuses of the CSU system, the number of activities offered by the individual programs differs according to their needs. That said, all campuses are required to offer activities focused on social integration, which includes continuous advising/counseling, communication, and activities that promote student cohesion.

During the 29 years of CSU-LSAMP programming, there has been notable progress in closing educational achievement gaps across race/ethnicity in California. In 2020, the average 6-year graduation rates for Hispanic and African American CSU-LSAMP participants were twice that of non-program participants of the same ethnic backgrounds. Among Hispanic participants, the 6-year graduation rate among CSU-LSAMP participants now exceeds that of non-UR students, and among African American participants, the gap has closed by more than 50%.

The first two 5-year phases of the CSU-LSAMP Alliance were focused on increasing the number of STEM baccalaureate degrees earned by students from underrepresented groups. Starting with the third 5-year phase (2004), the program expanded its focus to include progression to STEM graduate degrees, which remained as the primary focus throughout the time period of the data used for this study (2004–2019). Also beginning in 2004, all program activities were codified, with campus coordinators being trained annually to ensure program fidelity, including consistent implementation across campuses, and consistent reporting.

In addition to social integration activities, campuses choose to emphasize either academic integration, professionalization, or both. Academic integration focuses on providing academic support in "gatekeeper" courses and facilitating academic transitions with the primary goal of improving preparation, performance, and qualifications for advancement to graduate programs in STEM. Professionalization focuses on providing research opportunities, internships, international activities, conference participation, and graduate school preparation activities. At this point, only one of the 23 campuses focuses only on academic integration. Smaller programs tend to emphasize professionalization.

As already alluded to, and critically for our study, undergraduate research experience (URE) is one of the most important interventions of the CSU-LSAMP program. URE has been a prominent and emphasized feature of the program, offered by all campuses throughout this study time period. Specifically, the LSAMP program provides opportunities for students in STEM disciplines to conduct original research outside the classroom under the guidance of a faculty member (either during the school year or over the summer), present that research at professional conferences, and pursue peer-reviewed publication.[3]

[3] For a full CSU-LSAMP program description, see the program's website: https://www.csus.edu/college/natural-sciences-mathematics/csu-lsamp/program-goals.html.

To be more precise, all CSU-LSAMP students who participate in URE are mentored by faculty members from over eight major STEM disciplines across the CSU. Faculty mentors guide CSU-LSAMP student researchers in student-led research projects and provide skills learned at laboratories for robotics, coding, analytical chemistry, molecular cell biology, petrography, material testing facilities, greenhouses and arboretums, museums, planetariums, and observatories, among others. Faculty mentors also encourage the presentation of research at national conferences, provide networking opportunities within their fields, facilitate the search of graduate programs, assist on graduate applications, and provide guidance on responsible research conduct. Moreover, CSU-LSAMP provides salaries, travel stipends, and funding for research supplies and assists participants in applying for external research funding.

Data, Research Design, and Analysis

For this study, we obtained CSU-LSAMP participant data across all 23 campuses from 2004 to 2019. We selected the study years 2004–2019 so as to restrict the analysis to the time period in which the program had been fully implemented across all campuses, with a common goal of progression to STEM graduate degrees. We included all student records that could be linked to those in the National Student Clearinghouse and the CSU's Enrollment Reporting System, in order to track the students' baccalaureate attainment and activities after graduating from a CSU.[4] The sample does not include any records of students who were not CSU-LSAMP participants, thereby holding several potentially confounding variables constant. In all, we analyzed 10,143 student participant records—7,457 who had entered a CSU as first-years and 2,686 who had entered as transfer students.

Demographically speaking, 53% of sample participants were self-identified as male, and the ethnic/racial composition of the sample was as follows: 68% of the former LSAMP participants were Hispanic/Latine, 12% were African American/Black, 7% were Asian American, 7% were White, 2% were Pacific Islander, 2% were Indigenous American, and 1% were multiracial.

Outcome Variables and Hypotheses

We analyzed three outcome variables: (1) STEM baccalaureate degree attainment, (2) post-baccalaureate enrollment, and (3) post-baccalaureate degree attainment in STEM. All three of these variables are dichotomous. Post-baccalaureate degrees in STEM include master's degrees and/or PhDs (degrees in humanities, social sciences, or education and medical degrees (M.D.s or nursing degrees) are excluded). Thus, formally stated, our specific hypotheses are as follows:

[4] We were able to obtain ERS data for 80% of CSU-LSAMP participants and NSC records for 68% of CSU-LSAMP participants. ERS data could not be obtained for CSU-LSAMP participants whose Web-AMP records were missing SSN. Students were matched to NSC data using name and birthdate. Students can also decline to share their data with the NSC, which accounts for the lower match rate with NSC data.

H_1: Among CSU-LSAMP program participants, those who participate in structured undergraduate research experience are more likely than those who do not to graduate with a baccalaureate degree in a STEM discipline.
H_2: Among CSU-LSAMP program participants, those who participate in structured undergraduate research experience are more likely than those who do not to enroll in a post-graduate degree program.
H_3: Among CSU-LSAMP program participants, those who participate in structured undergraduate research experience are more likely than those who do not to graduate with a post-graduate degree in STEM.

Statistical Analysis: URE vs. Non-URE Matching Procedure

Because CSU-LSAMP students choose whether to participate in URE, a randomized controlled experimental design was not feasible for this study. Thus, we employed a quasi-experimental design that approximated "treatment" and "control" groups by using propensity score matching with inverse probability weights (Austin & Stuart, 2015).[5] The matching estimator approximates a causal estimate of the impact of URE on student outcomes if selection into URE is conditionally independent of potential outcomes.[6]

Specifically, we matched URE participants and non-URE participants on a large number of student- and campus-level characteristics. The student-level characteristics were as follows: race/ethnicity, gender identity, age, college major, class level at entry (freshman, sophomore, etc.), Pell Grant eligibility, and academic preparedness (SAT score and high school GPA for entering first-year students; transfer GPA for transfer students). The campus-level characteristics were as follows: LSAMP program size, LSAMP program emphasis (professionalization or dual emphasis), campus student enrollment, campus commuter rate (percentage of students who live off campus), campus urbanicity, campus acceptance rate, campus percentage of faculty who are White, and campus percentage of White students. Measurement details and descriptive statistics (means, standard deviations) for all of these variables appear in Appendix 1 (Table 1).

As Appendix 2 displays, with respect to those student-level and campus-level variables, the matching procedure produced essentially identical categories of students who had participated in URE/not participated in URE for analysis; the mean

[5] We use a simplified measure of URE, rather than one that measures differences in duration of participation (e.g., multiple years vs. one), because the matching method we employed is much more complicated if attempting to equalize three groups (non-URE, 1 year of URE, 2 or more years of URE) instead of just two, making us much more confident in the stability of the estimates when using this simplified procedure. However, it is worth pointing out that in preliminary statistical analyses in which we simply include the matching variables as model covariates, we did include a 3-point measure of URE that distinguishes those who participated in such research activities for only 1 year and those who participated for 2 or more years. Those models reveal that, generally speaking, such additional URE "dosage" slightly strengthens the size of the coefficients associated with URE participation. Thus, the estimates we report below may be considered conservative.

[6] As a robustness test, we also estimated models using the nearest neighbor method of matching. We did so repeatedly, specifying that the procedure use 1 and 10 "nearest neighbors" to match. The results we obtained look highly similar, in terms of both substantive and statistical significance, to those we report here.

standardized difference between the two groups, across all variables, for traditional students (Table 2) is 0.01 (0.02 for transfer students in Table 3), with no standardized difference between URE students and non-URE students being greater than 0.03 (0.04 for transfer students). By comparison, before conducting the propensity score matching procedure (as Appendix 2 also shows), the mean standardized difference between URE students and non-URE students in Table 2 across all of these potentially confounding influences for traditional students was 0.12 (0.09 for transfer students, presented in Table 3), with several differences being greater than 0.2.

Statistical Analysis: Model Estimation

After creating the matched dataset, to test our hypotheses, we estimated a series of probit regression models (in light of the fact that all of our outcome variables are dichotomous; see Hahn & Soyer, 2005).[7] We analyzed students who entered a CSU as traditional students separately from those who entered as transfer students. Full model specifications are displayed in Appendix 3, with Table 4 presenting results for traditional students and Table 5 for transfer students.

Despite matching the comparison groups based on all of the potential confounding variables we listed earlier, we also included all of those variables as covariates in our models so as to observe their independent predictive capacities. By including all of these covariates in addition to performing the matching procedure, we estimated "doubly robust" regression models (Morgan & Winship, 2014).

To account for the hierarchical nature of the data—with student observations grouped within campus-level observations—we clustered standard errors at the campus level.[8] In light of our large sample size, we deleted cases from the analysis if they had missing data on any individual variable (the listwise deletion method).

To ease interpretation of the probit coefficients, we converted them to differences in the predicted probability of the desired outcome in question that are associated with one-unit increases in the explanatory variables.

Results

Figures 1 and 2 display the results as they pertain to our first hypothesis, baccalaureate attainment in STEM. Among the students in our sample who entered a CSU as first-year students and took part in the LSAMP program but did not participate in URE, as Fig. 1

[7] As another robustness check, in alternative model estimations, we used the complementary log-log estimator in light of the varying degrees of skew associated with our outcome variables. The results did not meaningfully differ, either substantively or statistically, in those models, so we report the probit results because probit regression is familiar to a broader audience of readers.

[8] Rather than an HLM model assuming random campus effects, in alternative models, we included "fixed effects" dummy variables for all the campuses to account for any selection bias associated with unobserved campus-level variables. Because doing so added multicollinearity to the models, causing some of the covariates to be dropped, we do not report those results here. However, importantly, the inclusion of campus fixed effects did not substantially alter any of the results we report below.

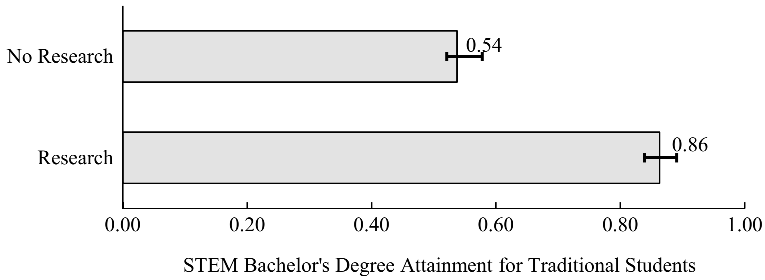

Fig. 1 Undergraduate research experience and STEM baccalaureate attainment: traditional students. Note. Bars represent the predicted probabilities of graduating with a baccalaureate degree in *STEM* among traditional students, as estimated from doubly robust binary probit models, after accounting for various other student/campus characteristics (see p. 10, above, for details). STEM represents 95% confidence intervals. Analyses performed in STATA (version 17)

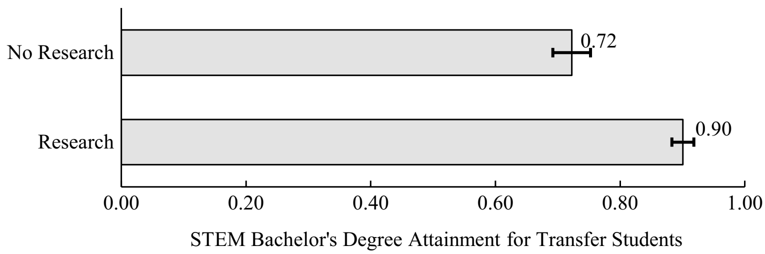

Fig. 2 Undergraduate research experience and STEM baccalaureate attainment: transfer students. Note. Bars represent the predicted probabilities of graduating with a baccalaureate degree in *STEM* among transfer students, as estimated from doubly robust binary probit models, after accounting for various other student/campus characteristics (see p. 10, above, for details). STEM represents 95% confidence intervals. Analyses performed in STATA (version 17)

shows, the probability of ultimately attaining a baccalaureate degree was 0.54. Among those first-year entrees who did participate in URE as part of their LSAMP portfolio, the probability jumped 32 percentage points to 0.86, after holding everything else constant ($p<0.001$).

A smaller but similar pattern holds among transfer students; URE corresponds to an 18 percentage-point increase in STEM baccalaureate attainment (from 0.72 to 0.90; $p<0.001$).[9]

What about URE and post-baccalaureate enrollment (H_2)?[10] Figure 3 shows that among students who enter a CSU in their first-year, URE is associated with a 19

[9] Additional analyses reveal that URE is also associated with increases in graduation rates in non-STEM fields, but the relationship is smaller.

[10] Unfortunately, limitations in data availability precluded us from analyzing post-graduate enrollment in STEM fields, specifically. Specifically, NSC enrollment data does not consistently provide the level of enrollment or discipline that information is only reflected in NSC records when a degree is awarded. If we had, we might have observed an even stronger relationship, given the other patterns of results we report here.

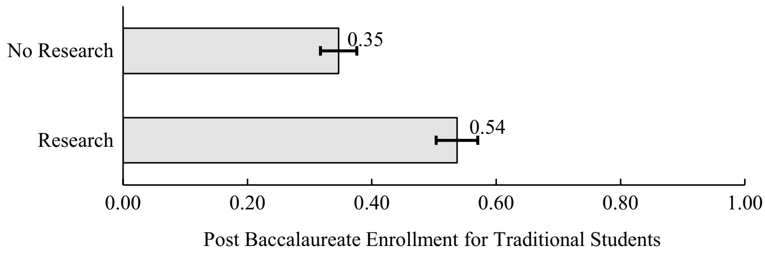

Fig. 3 Undergraduate research experience and post-baccalaureate enrollment: traditional students. Note. Bars represent the predicted probabilities of enrolling in a post-baccalaureate degree program among traditional students, as estimated from doubly robust binary probit models, after accounting for various other student/campus characteristics (see p. 10, above, for details). STEM represents 95% confidence intervals. Analyses performed in STATA (version 17)

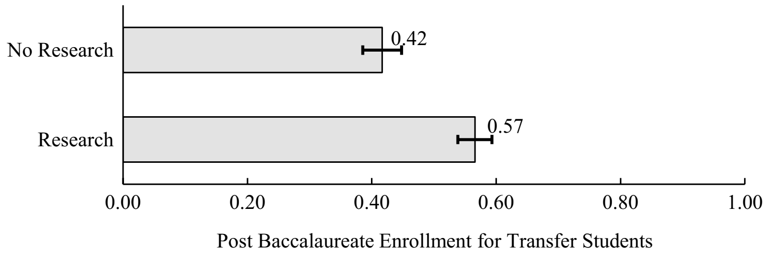

Fig. 4 Undergraduate research experience and post-baccalaureate enrollment: transfer students. Note. Bars represent the predicted probabilities of enrolling in a post-baccalaureate degree program among transfer students, as estimated from doubly robust binary probit models, after accounting for various other student/campus characteristics (see p. 10, above, for details). STEM represents 95% confidence intervals. Analyses performed in STATA (version 17)

percentage-point boost in such enrollment (from 0.35 to 0.54), holding everything else constant.

Similarly, Fig. 4 shows that among transfer students, URE is associated with a fifteen percentage-point increase in post-baccalaureate enrollment (from 0.42 to 0.57; p<0.001).

Finally, and perhaps most pertinently, to what extent is URE is independently predictive of post-graduate attainment in a STEM discipline (H_3)? As Figs. 5 and 6 display, LSAMP students who participate in URE are about nine percentage points more likely to eventually graduate with a post-graduate degree in STEM. This is true among students who enter as first-years (0.06 to 0.15; p<0.001) as well as among transfer students (0.09 to 0.17; p<0.001).[11]

[11] Additional analyses reveal that URE is also associated with post-graduate degree attainment in non-STEM fields, though the relationship is smaller.

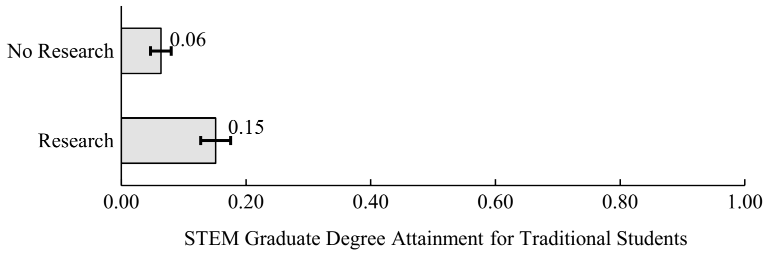

Fig. 5 Undergraduate research experience and STEM post-baccalaureate attainment: traditional students. Note. Bars represent the predicted probabilities of graduating with a post-baccalaureate degree in *STEM* among traditional students, as estimated from doubly robust binary probit models, after accounting for various other student/campus characteristics (see p. 10, above, for details). STEM represents 95% confidence intervals. Analyses performed in STATA (version 17)

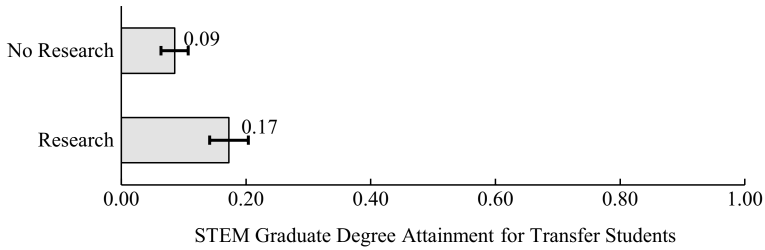

Fig. 6 Undergraduate research experience and STEM post-baccalaureate attainment: transfer students. Note. Bars represent the predicted probabilities of graduating with a post-baccalaureate degree in *STEM* among transfer students, as estimated from doubly robust binary probit models, after accounting for various other student/campus characteristics (see p. 10, above, for details). STEM represents 95% confidence intervals. Analyses performed in STATA (version 17)

Conclusion

Reducing racial/ethnic disparities in STEM post-graduate educational achievement is critically important for several reasons. First, it is vital to maximizing scientific output and therefore to the advancement of knowledge; if large swaths of the US population are not represented in STEM fields, the perspectives that are brought to bear in those fields will remain limited, thereby restricting the range of discoveries that can be made. Second, reducing such disparities is crucial to maximizing economic growth and minimizing poverty. Increasingly, in the ever-expanding "knowledge economy," STEM degrees offer virtually unrivaled employment opportunities and earning potential, which fuel overall GDP gains. Third, and relatedly, reducing those disparities is essential to reducing economic and social inequalities more generally.

Accordingly, education researchers have invested considerable energy into understanding the roots of those attainment gaps and how to reduce them. Substantial evidence points to sociological and psychological culprits; many underrepresented students lack successful role models in STEM fields, which damages their perceptions of self-efficacy and belonging, thereby weakening their tendency to persist when inevitable challenges arise. Thus, diversifying the STEM workforce—perhaps especially among university faculty—will have indirect, long-term benefits on all of these dimensions that can become self-perpetuating, as students from underrepresented backgrounds gain more role models in these positions.

What interventions may succeed in addressing these goals? One possibility is to give students hands-on research experience as undergraduates, outside the classroom, structured in coordination with a faculty advisor. Such URE may demystify the nuts and bolts of scientific research, making it less intimidating and breeding confidence, which may spark deeper interest and investment. Extant scholarship provides evidence of such outcomes and corresponding intentions to pursue graduate studies in STEM. However, due to data limitations, hard evidence of a connection between URE and post-graduate achievement in STEM is scant. This investigation attempts to make some progress toward filling that scholarly gap.

We draw upon institutional student data from the California State University (23 campuses) system's implementation of the Louis Stokes Alliance for Minority Participation program (CSU-LSAMP)—one of the largest and longest-standing intervention of this kind in the USA—and we link those data to student records from the National Student Clearinghouse and the CSU's Enrollment Reporting System in order track post-graduate degree enrollment and attainment. The large sample (n=10,143 students, across 23 CSU campuses, from 2004 to 2019) offers a degree of generalizability to our research design that has not previously been possible. Moreover, we gain causal leverage over our hypotheses by (a) holding non-URE interventions constant by restricting the sample to LSAMP program participants; (b) matching students who participated in URE and those who did not on a host of covariates, effectively equalizing the quasi-treatment and control groups on a wide array of individual and campus-level characteristics that could influence self-selection to participate in URE; (c) including those potential confounding variables in our prediction models to perform "doubly robust" probit regression analyses; and (d) analyzing traditional students (those who entered a CSU in their first-years) and transfer students separately, conceptualizing them as fundamentally distinct populations.

The data are strongly consistent with hypotheses connecting URE with STEM persistence among students from underrepresented groups. To be precise, among both traditional students and transfer students, we find substantial associations between URE and (1) baccalaureate attainment in STEM, (2) enrollment in a post-graduate degree program, and (3) graduation with a post-graduate degree in STEM. These relationships are all highly robust to various alternative model specifications, analytical choices, and sample restrictions. Of course, this study remains limited in that, despite the causal leverage we were able to gain from our quasi-experimental design, we still cannot be definitively confident that URE *caused* STEM higher educational persistence without randomly assigning some students to participate in URE and others to not.

A primary advantage of our study design is the comprehensive data we employ from the CSU-LSAMP program. The California State University system is among the largest in the world, educating students in a state with a large economy that is a global leader in science and technology research and industry. Lessons about the importance of URE participation for bolstering persistence in STEM majors for underrepresented groups here are germane to efforts with the same ends in other settings. Supporting historically underrepresented groups in STEM education is a topic of importance globally, including Asia, Australia, Canada, and Europe (Almukhambetova & Kuzhabekova, 2021; Isphording & Qendrai, 2019; Professionals Australia, 2018; Watt et al., 2012). Examples and guidelines for providing undergraduate research opportunities are many (Fakayode et al., 2014; Govindan et al., 2020; McGill et al., 2021). Our findings suggest that such efforts can have substantial impact.

Moreover, several questions remain for future research. For example, because our data could not capture the granularity of semesters of URE participation, it is not clear whether different levels of URE "dosage" would be associated with larger/smaller increases in STEM educational persistence. Is one semester/summer as good as two or three semesters/summers, or is more always better? We also cannot determine from this investigation the extent to which the relationships between URE and STEM educational persistence are constant across gender, race/ethnicity (e.g., among African Americans vs. Hispanic Americans), college major (e.g., math vs. biology vs. physical science vs. engineering), or other potential modifiers. Finally, our data cannot reveal the precise mechanism that is driving the relationships between URE and STEM persistence among traditionally underrepresented students. Is it due to increases in perceptions of scientific self-efficacy? Increases in feelings of belonging? Both? Or something else? Determining those mechanisms would require pairing institutional data such as that which we obtained for CSU-LSAMP with student surveys taken at the time. In recent years, the CSU-LSAMP has been conducting those surveys, but the institutional data that is needed will not be available for some time as those students will need time to complete STEM graduate degrees. We encourage other researchers to pursue these lines of inquiry.

Appendix 1

This section describes all variables used in the analysis. Table 1 displays descriptive statistics for all variables.

Student Characteristics

Undergraduate research experience: undergraduate research experience outside of the classroom under the guidance of a faculty mentor. This variable is coded 0|1, with 1 representing one or more years of URE.

STEM bachelor's degree: this variable is coded 0|1, with 1 representing completion of a STEM bachelor's degree.

Post-baccalaureate enrollment: this variable is coded 0|1, with 1 representing enrollment following completion of a bachelor's degree. NSC enrollment data does not consistently provide the level of enrollment or discipline; that information is only reflected in NSC records when a degree is awarded.

STEM graduate degree: This variable is coded 0|1, with 1 representing completion of a STEM masters or doctoral degree.

Major: all CSU-LSAMP students are STEM majors (or considering a STEM major). Dummy variables (0|1) were created for biology, math, physical sciences, computer science, engineering/engineering technologies, and natural resources and conservation. All other STEM majors were used as the reference category.
Gender: 0= male, 1 =female.
Pell eligibility: dummy variable is coded as 0 = not Pell eligible and 1 = Pell eligible.
Age at CSU entry: continuous age at CSU entry.
Race/ethnicity: dummy variables (0|1) were created for all race/ethnicity categories. Hispanic students of all races are coded as Hispanic. The non-Hispanic multiracial UR category includes students who identified themselves as multiracial, where at least one race category was Black, Native American, or Pacific Islander. The non-Hispanic multiracial non-UR category includes students who identified themselves as White and Asian. Non-Hispanic Whites were used as the reference category. Six non-Hispanic multiracial non-UR transfer students were dropped from the transfer student sample as none had participated in URE, and no weights could be generated for them.
Academic preparedness: for traditional students, SAT scores and HS GPA scores were converted to standard deviation units (with a mean of zero and a standard deviation of 1). This was accomplished by simply subtracting the mean from each observation in the variable and then dividing it by its standard deviation. Then, these two variables were summed into an index. Then, the resulting two-item index was converted to a 0-1 scale, by adding the lowest value of the variable to each observation (that brought the lowest observation up to 0) and then dividing by the highest value. For transfer students, transfer GPA was used, as SAT scores and HS GPA were not available.
Class at CSU entry: dummy variables (0|1) were created for each class level at entry (freshman, sophomore, junior, and senior).

Campus Variables

CSU-LSAMP program size: total number of program participants at each campus 2021.
Total enrollment: total campus enrollment in fall 2020.
Students in off-campus housing: proportion of students in off-campus housing.
Acceptance rate: proportion of students who applied who were admitted to each campus.
Urbanicity: dummy variables (0|1) were created for rural, suburban, and urban campuses. Rural is used as the reference category.
Program emphasis (URE implementation): CSU-LSAMP programs can select one of three program emphases: academic (focused student success), professionalization (focused on graduate school preparation and URE), and dual emphasis (both academic and professionalization). Only one campus had an academic focus, California Maritime Academy, a small program with very few research participants. This campus was grouped with the dual campuses in the reference category.
Proportion of White faculty: proportion of full-time instructional staff who were White in 2020, data comes from the IPEDS survey.
Proportion of White students: proportion of students who were White in 2020.

Table 1 Means and standard deviations for all variables

	Traditional students		Transfer students	
	n= 7,457		*n*=2,686	
	Mean	SD	Mean	SD
Student variables				
Undergraduate research experience	0.31	0.46	0.40	0.49
STEM bachelor's degree	0.63	0.48	0.78	0.42
Post-bac enrollment	0.41	0.49	0.47	0.50
STEM graduate degree	0.10	0.29	0.13	0.34
Biological sciences	0.32	0.47	0.39	0.49
Math	0.08	0.27	0.07	0.26
Physical sciences	0.13	0.34	0.20	0.40
Computer science	0.07	0.26	0.06	0.23
Engineering/engineering technologies	0.36	0.48	0.21	0.41
Natural resources and conservation	0.02	0.15	0.04	0.20
Female	0.47	0.50	0.48	0.50
Pell eligible	0.63	0.48	0.67	0.47
Age at CSU entry	18.17	0.56	24.41	4.57
Hispanic (all races)	0.70	0.46	0.63	0.48
Non-Hispanic Black	0.12	0.33	0.10	0.29
Non-Hispanic American Indian	0.01	0.10	0.03	0.17
Non-Hispanic Pacific Islander	0.02	0.15	0.02	0.14
Non-Hispanic multiracial UR	0.01	0.10	0.01	0.12
Non-Hispanic Asian	0.07	0.25	0.08	0.27
Non-Hispanic multiracial non-UR	0.00	0.05	0.00	0.00
Race not reported	0.01	0.11	0.02	0.13
Academic preparedness (SAT and HS GPA)	0.69	0.08	3.03	0.48
Freshman at CSU entry	0.97	0.17	--	--
Academic preparedness (transfer GPA)	--	--	3.03	0.48
Junior at CSU entry	--	--	0.64	0.48
Campus variables				
CSU-LSAMP program size	145.90	120.14	141.23	126.39
Total enrollment	24641.13	10144.68	22275.46	10393.61
Proportion of students in off-campus housing	0.86	0.19	0.84	0.21
Acceptance rate	0.73	0.16	0.74	0.17
Urban	0.57	0.50	0.56	0.50
Suburban	0.33	0.47	0.35	0.48
Professionalization emphasis	0.52	0.50	0.60	0.49
Proportion of faculty who are White	0.56	0.09	0.56	0.10
Proportion of students who are White	0.22	0.13	0.21	0.14

Appendix 2. Balance tables

Table 2 Unweighted and weighted means for URE non-participants and participants: traditional students

	Unweighted means				Weighted means			
	Research	No research	Raw difference	Std. difference	Research	No research	Raw difference	Std. difference
Student variables								
Biological sciences	0.39	0.29	0.10	0.22	0.39	0.40	−0.01	−0.02
Mathematics	0.06	0.09	−0.03	−0.13	0.06	0.06	0.00	0.00
Physical sciences	0.21	0.10	0.11	0.30	0.21	0.22	−0.01	−0.03
Computer science	0.05	0.08	−0.03	−0.15	0.05	0.05	0.00	0.00
Engineering/engineering technologies	0.26	0.40	−0.14	−0.30	0.26	0.25	0.01	0.04
Natural resources and conservation	0.03	0.02	0.01	0.03	0.03	0.03	0.00	0.00
Female	0.52	0.45	0.07	0.15	0.52	0.53	−0.01	−0.01
Pell eligible	0.63	0.63	0.00	0.00	0.63	0.64	−0.01	−0.02
Age at CSU entry	18.16	18.18	−0.02	−0.04	18.16	18.15	0.01	0.01
Hispanic (all races)	0.67	0.72	−0.05	−0.10	0.67	0.67	0.00	0.01
Non-Hispanic Black	0.09	0.14	−0.05	−0.15	0.09	0.09	0.00	0.01
Non-Hispanic American Indian	0.01	0.01	0.00	−0.05	0.01	0.01	0.00	−0.01
Non-Hispanic Pacific Islander	0.03	0.02	0.01	0.09	0.03	0.03	0.00	0.02
Non-Hispanic multiracial UR	0.01	0.01	0.00	0.03	0.01	0.01	0.00	0.00
Non-Hispanic Asian	0.10	0.05	0.05	0.18	0.10	0.11	−0.01	−0.03
Non-Hispanic multiracial non-UR	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.01
Race not reported	0.01	0.01	0.00	0.03	0.01	0.02	−0.01	−0.01
Academic preparedness (SAT and HS GPA)	0.71	0.68	0.03	0.25	0.71	0.71	0.00	0.00
Freshman at CSU entry	0.95	0.98	−0.03	−0.12	0.95	0.95	0.00	0.00

Table 2 (continued)

	Unweighted means				Weighted means			
	Research	No research	Raw difference	Std. difference	Research	No research	Raw difference	Std. difference
Campus variables								
CSU-LSAMP program size	176.53	131.93	44.60	0.35	176.53	180.54	−4.01	−0.03
Total enrollment	23937.15	24962.25	−1025.10	−0.10	23937.15	23829.46	107.69	0.01
Students in off-campus housing	0.86	0.86	0.00	−0.02	0.86	0.86	0.00	−0.02
Acceptance rate	0.73	0.73	0.00	0.03	0.73	0.74	−0.01	−0.02
Urban	0.61	0.55	0.06	0.12	0.61	0.61	0.00	−0.01
Suburban	0.31	0.33	−0.02	−0.04	0.31	0.30	0.01	0.04
Professionalization emphasis	0.52	0.52	0.00	0.02	0.52	0.51	0.01	0.03
Proportion of faculty who are White	0.54	0.56	−0.02	−0.25	0.54	0.54	0.00	0.00
Proportion of students who are White	0.20	0.22	−0.02	−0.17	0.20	0.20	0.00	0.01
Mean standard difference				0.12				0.01

Results from propensity score matching procedure using inverse probability weights. Analyses performed in STATA (version 17)

Table 3 Unweighted and weighted means for URE non-participants and participants: transfer students

	Unweighted means				Weighted means			
	Research	No research	Raw difference	Std. difference	Research	No research	Raw difference	Std. difference
Student variables								
Biological sciences	0.44	0.36	0.08	0.15	0.44	0.43	0.01	0.02
Mathematics	0.04	0.09	−0.05	−0.22	0.04	0.05	−0.01	−0.03
Physical sciences	0.28	0.15	0.13	0.30	0.28	0.27	0.01	0.00
Computer science	0.04	0.07	−0.03	−0.16	0.04	0.04	0.00	−0.01
Engineering/engineering technologies	0.16	0.25	−0.09	−0.25	0.16	0.16	0.00	−0.01
Natural resources and conservation	0.04	0.04	0.00	−0.01	0.04	0.04	0.00	0.00
Female	0.51	0.47	0.04	0.07	0.51	0.50	0.01	0.01
Pell eligible	0.69	0.66	0.03	0.07	0.69	0.70	−0.01	−0.02
Age at CSU entry	24.15	24.58	−0.43	−0.09	24.15	24.20	−0.05	−0.01
Hispanic (all races)	0.61	0.65	−0.04	−0.08	0.61	0.61	0.00	0.00
Non-Hispanic Black	0.07	0.11	−0.04	−0.12	0.07	0.07	0.00	0.00
Non-Hispanic American Indian	0.03	0.03	0.00	−0.05	0.03	0.03	0.00	−0.01
Non-Hispanic Pacific Islander	0.02	0.02	0.00	−0.01	0.02	0.02	0.00	0.02
Non-Hispanic multiracial UR	0.02	0.01	0.01	0.04	0.02	0.02	0.00	0.01
Non-Hispanic Asian	0.09	0.07	0.02	0.08	0.09	0.09	0.00	−0.01
Race not reported	0.02	0.01	0.01	0.07	0.02	0.02	0.00	0.01
Academic preparedness (transfer GPA)	3.06	3.01	0.05	0.11	3.06	3.05	0.01	0.03
Junior at CSU entry	0.64	0.64	0.00	0.00	0.64	0.65	−0.01	−0.02
Campus variables								
CSU-LSAMP program size	147.91	136.74	11.17	0.09	147.91	153.36	−5.45	−0.04
Total enrollment	22471.97	22143.32	328.65	0.03	22471.97	22625.68	−153.71	−0.02
Students in off-campus housing	0.83	0.84	−0.01	−0.07	0.83	0.84	−0.01	−0.02

Table 3 (continued)

	Unweighted means				Weighted means			
	Research	No research	Raw difference	Std. difference	Research	No research	Raw difference	Std. difference
Acceptance rate	0.73	0.75	−0.02	−0.13	0.73	0.72	0.01	0.03
Urban	0.54	0.57	−0.03	−0.04	0.54	0.54	0.00	0.01
Suburban	0.37	0.33	0.04	0.09	0.37	0.37	0.00	0.01
Professionalization emphasis	0.64	0.58	0.06	0.14	0.64	0.63	0.01	0.02
Proportion of faculty who are White	0.55	0.56	−0.01	−0.02	0.55	0.56	−0.01	−0.02
Proportion of students who are White	0.22	0.21	0.01	0.03	0.22	0.22	0.00	−0.02
Mean standard difference				0.09				0.02

Results from propensity score matching procedure using inverse probability weights. Analyses performed in STATA (version 17)

Appendix 3. Full results

Table 4 URE and STEM educational achievement: traditional students

	STEM bach degree dF/dx (S.E.)	Post-bac enrollment dF/dx (S.E.)	STEM grad degree dF/dx (S.E.)
Student variables			
Undergraduate research experience	0.32 (0.01)*	0.19 (0.01)*	0.09 (0.01)*
Biological sciences	0.05 (0.06)	0.08 (0.07)	0.02 (0.05)
Math	0.06 (0.06)	0.03 (0.07)	0.13 (0.09)
Physical sciences	0.06 (0.06)	0.06 (0.07)	0.06 (0.06)
Computer science	−0.04 (0.07)	−0.18 (0.06)*	−0.01 (0.05)
Engineering/engineering technologies	0.07 (0.06)	−0.09 (0.07)	0.05 (0.06)
Natural resources and conservation	0.04 (0.07)	0.00 (0.08)	0.06 (0.08)
Female	−0.02 (0.01)	0.06 (0.02)*	−0.01 (0.01)
Pell eligible	−0.03 (0.01)*	0.02 (0.02)	−0.02 (0.01)
Age at CSU entry	−0.03 (0.01)*	0.00 (0.01)	0.00 (0.01)
Hispanic (all races)	−0.19 (0.03)*	−0.10 (0.03)*	−0.06 (0.02)*
Non-Hispanic Black	−0.26 (0.05)*	−0.08 (0.04)*	−0.03 (0.02)
Non-Hispanic American Indian	−0.23 (0.08)*	−0.18 (0.07)*	−0.03 (0.04)
Non-Hispanic Pacific Islander	−0.09 (0.06)	−0.11 (0.05)*	−0.02 (0.03)
Non-Hispanic multiracial UR	−0.21 (0.08)*	−0.14 (0.06)*	−0.06 (0.02)
Non-Hispanic Asian	−0.11 (0.05)*	−0.05 (0.04)	−0.04 (0.02)
Non-Hispanic multiracial non-UR	−0.11 (0.14)	−0.01 (0.14)	−0.09 (0.02)*
Race not reported	−0.12 (0.08)	−0.10 (0.07)	−0.05 (0.02)
Academic preparedness	0.66 (0.10)*	0.71 (0.11)*	0.43 (0.08)*
Freshman at CSU entry	0.02 (0.04)	−0.04 (0.04)	0.01 (0.02)
Campus variables			
CSU-LSAMP program size	0.00 (0.00)*	0.00 (0.00)*	0.00 (0.00)*
Total enrollment	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Students in off-campus housing	−0.05 (0.04)	−0.17 (0.05)*	−0.02 (0.03)
Acceptance rate	−0.17 (0.07)*	0.02 (0.08)	−0.03 (0.05)
Urban	−0.11 (0.04)*	−0.05 (0.05)	0.00 (0.03)
Suburban	−0.07 (0.04)*	−0.02 (0.04)	−0.01 (0.02)
Professionalization emphasis	0.03 (0.02)	0.02 (0.02)	0.01 (0.01)
Proportion of faculty who are White	−0.49 (0.28)	0.09 (0.31)	−0.14 (0.18)
Proportion of students who are White	−0.15 (0.19)	−0.29 (0.22)	−0.04 (0.13)
n=7,457			

Probit regression models. dF/dx coefficients are differences in the predicted probability of the outcome variable in question equaling “one” vs. “zero” that are associated with minimum-to-maximum differences in the explanatory variables. All standard errors (S.E.) are clustered by CSU campus. All analyses performed in STATA (version 17)

*p<0.05 (two-tailed test)

Table 5 Full probit model results for transfer students

	STEM bach degree dF/dx (S.E.)	Post-bac enrollment dF/dx (S.E.)	STEM grad degree dF/dx (S.E.)
Student variables			
Undergraduate research experience	0.18 (0.02)*	0.15 (0.02)*	0.09 (0.01)*
Biological sciences	0.19 (0.05)	0.08 (0.07)	0.14 (0.08)
Math	0.15 (0.02)	0.16 (0.08)*	0.33 (0.14)*
Physical sciences	0.16 (0.04)	0.08 (0.07)	0.18 (0.10)*
Computer science	0.13 (0.03)	−0.12 (0.09)	0.09 (0.11)
Engineering/engineering technologies	0.20 (0.02)	−0.05 (0.08)	0.18 (0.12)
Natural resources and conservation	0.11 (0.03)	−0.09 (0.09)	0.13 (0.12)
Female	−0.05 (0.02)	0.00 (0.02)	0.01 (0.01)
Pell eligible	−0.02 (0.02)	0.03 (0.02)	−0.04 (0.02)*
Age at CSU entry	−0.01 (0.00)*	−0.01 (0.00)*	0.00 (0.00)
Hispanic (all races)	−0.10 (0.03)*	−0.04 (0.04)	−0.03 (0.02)
Non-Hispanic Black	−0.15 (0.05)*	−0.09 (0.05)	0.00 (0.03)
Non-Hispanic American Indian	−0.15 (0.07)	−0.06 (0.08)	−0.02 (0.04)
Non-Hispanic Pacific Islander	−0.04 (0.07)	0.04 (0.08)	0.09 (0.06)
Non-Hispanic multiracial UR	−0.13 (0.10)	0.00 (0.10)	−0.01 (0.06)
Non-Hispanic Asian	−0.05 (0.05)	−0.08 (0.05)	−0.09 (0.02)*
Race not reported	0.04 (0.07)	0.01 (0.09)	−0.04 (0.04)
Academic preparedness (transfer GPA)	0.08 (0.02)*	0.11 (0.03)*	0.03 (0.02)
Junior at CSU entry	0.01 (0.02)	0.00 (0.02)	−0.01 (0.02)
Campus variables			
CSU-LSAMP program size	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Total enrollment	0.00 (0.00)	0.00 (0.00)*	0.00 (0.00)*
Students in off-campus housing	0.00 (0.05)	−0.09 (0.07)	0.13 (0.05)*
Acceptance rate	0.15 (0.10)	0.34 (0.13)*	0.14 (0.08)
Urban	−0.18 (0.06)	−0.11 (0.08)	−0.08 (0.05)
Suburban	−0.04 (0.05)	0.01 (0.06)	−0.02 (0.04)
Professionalization emphasis	−0.05 (0.03)	−0.06 (0.04)	0.00 (0.02)
Proportion of faculty who are White	−0.06 (0.32)	−0.56 (0.45)	−0.82 (0.30)*
Proportion of students who are White	−0.16 (0.23)	0.27 (0.33)	0.44 (0.22)*
n=2,686			

Probit regression models. dF/dx coefficients are differences in the predicted probability of the outcome variable in question equaling “one” vs. “zero” that are associated with minimum-to-maximum differences in the explanatory variables. All standard errors (S.E.) are clustered by CSU campus. All analyses performed in STATA (version 17)

*p<0.05 (two-tailed test)

Declarations

Competing Interests The authors declare no competing interests.

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