California Education Learning Lab

Sources of Enrollment and Completion Gaps in STEM Higher Education

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This brief surveys academic research and literature on the sources of equity gaps in STEM higher education.

Significant gaps by gender and ethnicity exist in undergraduate STEM enrollment and completion. The first brief in this series, *Enrollment and Completion Gaps in California STEM Higher Education*, surveyed the extent of enrollment and completion gaps in California's systems of public higher education and detailed the extent to which female, Latinx, and African-American students are underrepresented in UC and CSU STEM enrollment and among STEM degree recipients. It also showed that smaller percentages of female and URM students enroll in STEM fields than do male and non-URM students and that rates of attrition from STEM fields are generally higher for female and URM students than they are for male and non-URM students.

These equity gaps are the product of significant barriers that deter students from entering and remaining in STEM fields. These barriers include:

1) **Opportunity gaps in K-12 education with regard to prior preparation for STEM fields**. Many URM students enter higher education less prepared for college-level STEM courses because of disparities in the quality of K-12 education and in access to advanced high school math and science courses. These disparities can also limit opportunities for underrepresented students to develop an interest in STEM.
2) **Traditional STEM pedagogy and curricula**. Students majoring in STEM confront a series of required introductory courses (e.g. math, chemistry, physics) in their first year, often with large enrollments. These courses typically feature instructional environments and standards that are very different from what students experienced in high school, and cover large amounts of material rapidly with limited individual support for students. Moreover, since these classes are seen as primarily preparing students with basic knowledge and tools for going on to more specialized and meaningful courses, the pedagogy and content tends to be traditional and uninspiring, while the academic demands are high. These courses function as gateways to STEM fields, and they have a large impact on the attrition of all potential STEM students. Their impact is greatest, however, on students who have less preparation and/or who may have questions as to whether they can succeed and whether they are welcome in STEM. The effect of all three of these factors tends to be greater on average for students from underrepresented groups compared to their non-underrepresented peers.
3) **Sociocultural factors**. Questions about whether they can succeed and are welcome in STEM are greater for female and URM students because of sociocultural factors. The classroom and disciplinary culture of STEM departments can be exclusive and unwelcoming to female and URM students. Cultural and disciplinary stereotypes about who is supposed or suited "to be a scientist" can negatively affect students' experience of specific course settings, and can also have broader impacts, like deterring students from entering or continuing in fields. The lack of diversity in STEM fields, meanwhile, can

deprive female and URM students of supportive communities and faculty role models. Programs that address such sociocultural factors by aiming to build supportive communities for underrepresented students and by helping to develop student identification with STEM disciplines have demonstrated significant success in fostering female and URM student persistence in STEM.

Opportunity Gaps and Prior Preparation

In part, STEM equity gaps arise from different levels of K-12 preparation for college-level science and math courses. In its 2013 report on STEM enrollment and persistence, the National Center for Education Statistics (NCES) found that 33 percent of STEM students whose highest high school math class was algebra II/trigonometry or pre-calculus switched majors. In comparison, only 24 percent of STEM students who took high school calculus switched to a non-STEM major.[1] Researchers studying STEM persistence among URM students have also found that the effects of ethnicity on student STEM persistence disappeared after controlling for high school academic achievement.[2]

Disparities also exist in access to advanced high school math and science courses. High schools that predominantly enroll African-American and Latinx students offer math and science courses at a lower rate than other high schools. Only 38 percent of high schools with enrollment that is more than 75 percent African-American or Latinx offer calculus, compared with 50 percent of all high schools.[3] As a result, Latinx and African-American students are much less likely to take high school calculus or advanced placement/IB science courses than white or Asian-American students.[4]

Such opportunity gaps affect STEM enrollment and persistence in multiple ways. Students without access to high quality K-12 science and math education will enter college with less proficiency in math. This has a disproportionate impact on success in STEM because success in introductory math courses is often set as a prerequisite to continuation in STEM.[5] Although most dramatic in math, the nature of the gateway introductory courses in general magnifies the differences in preparation in the respective subject when it comes to student outcomes. Having weaker high school math and science education also makes students less likely to acquire the scientific or technological interests that may encourage them to pursue STEM education or lead them to develop a personal identification with a STEM field.

Critically, all students bring a variety of strengths and weaknesses to their college experience. Prior preparation is only one of many issues that colleges need to better address to maximize the success of female

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[1] Xianglei Chen and Matthew Soldner, *STEM Attrition: College Students' Paths Into and Out of STEM Fields* (National Center for Education Statistics, November 2013), p. 17. Retrieved from: https://nces.ed.gov/pubs2014/2014001rev.pdf.

[2] Mitchell J. Chang, et al., "What Matters in College for Retaining Aspiring Scientists and Engineers from Underrepresented Racial Groups," *Journal of Research in Science Teaching* 51, no. 5 (2014): 555-580, at p. 565.

[3] U.S. Department of Education Office of Civil Rights, *2015-16 Civil Rights Data Collection: STEM Course Taking*, https://www2.ed.gov/about/offices/list/ocr/docs/stem-course-taking.pdf.

[4] National Science Board, *Science & Engineering Indicators, 2018*, Chapter 1, "Elementary and Secondary Mathematics and Science Education," https://nsf.gov/statistics/2018/nsb20181/report/sections/elementary-and-secondary-mathematics-and-science-education/high-school-coursetaking-in-mathematics-and-science.

[5] Lindsey E. Malcolm-Piqueux and Shirley M. Malcolm, "Engineering Diversity: Fixing the Educational System to Promote Equity," *The Bridge* 43 (Spring 2013), https://www.nae.edu/19582/Bridge/69735/69743.aspx; Shirley Malcolm and Michael Feder, Eds., *Barriers and Opportunities for 2-Year and 4-Year STEM Degrees: Systemic Change to Support Students' Diverse Pathways* (Washington, DC: The National Academies Pres, 2016), pp. 64-5.

and URM students in STEM. Research suggests that other factors play an equal or greater role in determining whether female and URM students persist in STEM, and has revealed correlations between particular pedagogical and student-support practices and increased rates of retention. One study found that for every 100-point increase in total SAT score, students were almost 7 percent more likely to persist in STEM. In comparison, however, URM students who participated in undergraduate research programs were 17.38 percent more likely to persist in STEM than students who did not participate in such programs; URM students who joined clubs relating to their major were 9.32 percent more likely to remain in STEM.[6] A study of persistence among Latinx students found that a 100-point increase in SAT score correlated to an increased likelihood of persisting in STEM of 3.54 percent. Conversely, membership in a STEM-related club correlated to a 15 percent increase in the likelihood of persisting in STEM and participation in undergraduate research programs correlated to a 19.51 percent increase in likelihood of persistence.[7]

Pedagogy and Curriculum

STEM curricula and pedagogy act as additional barriers to persistence and success. "Many students who transfer out of STEM majors perform well, but they describe the teaching methods and atmosphere in introductory STEM classes as ineffective and uninspiring."[8] Researchers and practitioners have emphasized the importance of revising approaches to pedagogy and curricula in STEM in order to improve both student persistence and learning outcomes.[9]

Education researchers, particularly in STEM fields, have found that students learn more when instructors use evidence-based teaching techniques that ask students to engage actively and cooperatively in classroom learning. Yet most STEM faculty continue to rely on traditional lecture-based teaching, where students listen passively. A nationwide survey of faculty at four-year institutions found that about two-thirds of faculty in STEM fields used extensive lecturing in all or most of their courses in 2014. STEM faculty also made extensive use of curve-based grading practices, which can contribute to perceptions of competition in the classroom and adversely affect URM students by exacerbating feelings of "racial isolation."[10] Almost half of engineering

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[6] Mitchell J. Chang, et al., "What Matters in College for Retaining Aspiring Scientists and Engineers from Underrepresented Racial Groups," *Journal of Research in Science Teaching* 51, no. 5 (2014), p. 567.

[7] Gina A. Garcia and Sylvia Hurtado, "Predicting Latina/o STEM Persistence at HSIs and non-HSIs," https://www.heri.ucla.edu/nih/downloads/AERA%202011%20-%20Garcia%20and%20Hurtado%20-%20Predicting%20Latino%20STEM%20Persistence.pdf.

[8] Adrianna Kezar and Elizabeth Holcombe, *Creating a Unified Community of Support: Increasing Success for Underrepresented Students in STEM—A Final Report on the CSU STEM Collaboratives Project* (USC Pullias Center for Higher Education, 2017). Retrieved from: https://pullias.usc.edu/csustemcollab/#report.

[9] Susan R. Singer, Natalie R. Nielsen, and Heidi A. Schweingruber, Eds., *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering* (Washington, DC: The National Academies, Press, 2012); Shirley Malcolm and Michael Feder, Eds., *Barriers and Opportunities for 2-Year and 4-Year STEM Degrees: Systemic Change to Support Students' Diverse Pathways* (Washington, DC: The National Academies Pres, 2016); Association of American Universities Undergraduate STEM Education Initiative, *Framework for Systemic Change in Undergraduate STEM Teaching and Learning*, https://www.aau.edu/sites/default/files/STEM%20Scholarship/AAU_Framework.pdf; Carl Wieman, *Improving How Universities Teach Science: Lessons from the Science Education Initiative* (Cambridge, MA: Harvard University Press, 2017)

[10] Bryce E. Hughes, Sylvia Hurtado and M. Kevin Eagan, "Driving Up or Dialing Down Competition in Introductory STEM Courses: Individual and Classroom Level Factors," (Washington, D.C., Association for the Study of Higher Education, November 2014), https://www.heri.ucla.edu/nih/downloads/ASHE2014-Competition-in-Introductory-STEM-Courses.pdf.

faculty and about a third of computer science and physical science faculty used curve grading in all or most courses.[11] Curve grading carries with it the underlying assumption that only a fixed fraction of any class is capable of being successful, irrespective of teaching quality, student preparation, or any other variables. [12] In contrast to the corrosive message this sends to students and faculty, STEM education researchers have clearly demonstrated that nearly all college students can be successful with the proper teaching and educational environment.

Problems of pedagogy in STEM are particularly apparent in the introductory gateway STEM courses. At 4-year colleges and universities, these courses tend to be taught in large lectures that provide students with few opportunities to engage actively with course material, or with one another, and that generally do not provide broad support for students.[13] This traditional approach to introductory courses tends to discourage STEM persistence across the board. Introductory courses in STEM fields often do little to connect course material to real-world contexts or applications or to explain how the information covered relates to students' wider interests. There is evidence that even well prepared students leave STEM because of their frustration with introductory course sequences and because they identify other fields that appear more interesting.[14]

The impact of demanding gateway courses and traditional pedagogical approaches is magnified, however, for less prepared students, including underrepresented students, who face the added barrier that they may also feel unwelcome or out-of-place in STEM classrooms. "One obstacle that underrepresented minority (URM) students face is overcoming a 'chilly' classroom climate, characterized by little student participation and faculty-driven transmission of information in large introductory classes."[15] The learning environment of STEM gateway courses can be dispiriting for all students, but it "disproportionately affects historically URM students, who face unique challenges resulting from feelings of social isolation, low confidence, and stereotype threat."[16] Significantly, teaching methods that have been shown to improve success for all students in gateway courses have been shown to offer additional benefits to URM students.[17]

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[11] Kevin Eagen, *Becoming More Student-Centered? An Examination of Faculty Teaching Practices across STEM and non-STEM Disciplines between 2004 and 2014* (Alfred P. Sloane Foundation, January 2016). Retrieved from: https://sloan.org/storage/app/media/programs/higher_education/science_of_learning_stem/Teaching%20STEM.pdf.

[12] Bryce E. Hughes, Sylvia Hurtado and M. Kevin Eagan, "Driving Up or Dialing Down Competition in Introductory STEM Courses: Individual and Classroom Level Factors," (Washington, D.C., Association for the Study of Higher Education, November 2014), https://www.heri.ucla.edu/nih/downloads/ASHE2014-Competition-in-Introductory-STEM-Courses.pdf.

[13] Josephine A. Gasiewski et al., "From Gatekeeping to Engagement: A Multicontextual, Mixed Method Study of Student Academic Engagement in Introductory STEM Courses," *Research in Higher Education* 53, no. 2 (2012): 229-261, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3596160/; Adrianna Kezar and Elizabeth Holcombe, *Creating a Unified Community of Support: Increasing Success for Underrepresented Students in STEM—A Final Report on the CSU STEM Collaboratives Project* (USC Pullias Center for Higher Education, 2017), p. 8. Retrieved from: https://pullias.usc.edu/csustemcollab/#report.

[14]Elaine Seymour and Nancy M. Hewitt, *Talking about Leaving: Why Undergraduates Leave the* Sciences (Boulder, CO: Westview Press, 1997).

[15] Cissy J. Ballen, "Enhancing Diversity in Undergraduate Science: Self-Efficacy Drive Performance Gains with Active Learning," *Life Sciences Education* 16 (Winter 2017), https://www.lifescied.org/doi/pdf/10.1187/cbe.16-12-0344.

[16] Cissy J. Ballen, "Enhancing Diversity in Undergraduate Science: Self-Efficacy Drive Performance Gains with Active Learning," *Life Sciences Education* 16 (Winter 2017), https://www.lifescied.org/doi/pdf/10.1187/cbe.16-12-0344.

[17] Scott Freeman, et al., "Active Learning Increases Student Performance in Science, Engineering, and Mathematics," *PNAS* 111, no. 23 (June 2014): 8410-8415, https://www.pnas.org/content/111/23/8410.

Sociocultural Factors

Disciplinary and departmental cultures play a role in contributing to attrition among URM and female students in STEM. Culture affects STEM participation and persistence in different ways and at multiple levels. Lack of racial and gender diversity within STEM disciplines, for example, can create an environment that is unwelcoming to underrepresented students, who confront an absence of role models and of peers who share a similar background.[18] Implicit biases, meanwhile, can shape how faculty and administrators interact with students (and how they advise student decision making) and affect how welcome students feel in the classroom.[19] STEM faculty and departments are starting to become aware of how these factors can impact URM students and their success, and of the importance of finding ways to make the atmosphere of their classrooms more inclusive.

Moreover, sociocultural stereotypes can limit students' exposure to and identification with STEM disciplines. For example, researchers observe how negative stereotypes about the math and science ability of female students and attitudes regarding "gender-appropriate" careers shape women's educational choices. Female students commonly rate their mathematical ability lower than their male peers do, even though actual competency levels are equivalent. This disparity in mathematical self-conception shapes students' intentions with regard to pursuing math-intensive STEM fields: although the percentage of female students taking advanced high school math courses is essentially the same, or higher, than the percentage of male students taking those courses, female students are significantly less likely to enter math-intensive and computer-related STEM fields than their male peers.[20] Researchers similarly emphasize the potential of stereotype threat—concern or anxiety of conforming to negative stereotypes about one's social group—to depress achievement among underrepresented students.[21]

In the face of such sociocultural barriers to diversity in STEM, researchers emphasize the importance of social and academic integration and the development of students' "science identity" to encourage persistence. Pedagogical strategies that give students opportunities to engage in research and to work closely with faculty members have increased student persistence. Programs that create supportive communities for underrepresented students have similarly improved outcomes for female and URM STEM students. "URM students who feel, think, behave, and are recognized by meaningful others (e.g., faculty role models) as 'science people,' are more confident about their academic abilities."[22]

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[18] Xianglei Chen and Matthew Soldner, *STEM Attrition: College Students' Paths Into and Out of STEM Fields* (National Center for Education Statistics, November 2013), p. 4; *Creating a Unified Community of Support.*

[19] Shirley Malcolm and Michael Feder, Eds., *Barriers and Opportunities for 2-Year and 4-Year STEM Degrees: Systemic Change to Support Students' Diverse Pathways* (Washington, DC: The National Academies Pres, 2016), pp. 66-72.

[20] National Science Board, *Science & Engineering Indicators, 2018*, Chapter 1, "Elementary and Secondary Mathematics and Science Education," https://nsf.gov/statistics/2018/nsb20181/report/sections/elementary-and-secondary-mathematics-and-science-education/high-school-coursetaking-in-mathematics-and-science. Public Policy Institute of California, "STEM Courses—Are California Students Taking College Prep Courses?" https://www.ppic.org/blog/tag/stem-courses/.

[21] Mitchell J. Chang, et al., "Stereotype Threat: Undermining the Persistence of Racial Minority Freshmen in the Sciences," https://heri.ucla.edu/nih/downloads/AERA%202009%20-%20Chang,%20Eagan,%20Lin,%20Hurtado%20-%20Stereotype%20Threat.pdf.

[22] Mitchell J. Chang, et al., "What Matters in College for Retaining Aspiring Scientists and Engineers from Underrepresented Racial Groups," *Journal of Research in Science Teaching* 51, no. 5 (2014), p. 557; Heidi B. Carlone and

Researchers also note that increasing female and URM student participation and persistence in STEM requires that disciplines and departments do more to engage with student interests. In addition to creating unwelcoming environments for female and URM students, disciplinary and departmental cultures can also deter student from entering or persisting in STEM fields by failing to engage with their priorities. Departmental emphasis on "pure" scientific research, and failure to inform students of the many more applied aspects of the discipline, can convey the idea of a traditional remote "science identity" and potentially deter female and URM students (as well as other students) who may prefer work that directly engages with people or that addresses social problems and community concerns.[23] As one education scholar observers with regard to computer science, "despite growing efforts to emphasize the broader impact of computing, students seeking to 'change the world' are continuing to seek other fields of study in college."[24] Research suggests that students from underrepresented groups are often particularly interested in engaging with issues or concerns facing their communities. For these students, non-STEM fields can appear to offer clearer paths to work that they see as rewarding.[25]

Conclusion

These various sources of equity gaps are intertwined and, for many students, they are often mutually reinforcing. "[S]witching from a STEM major to a non-STEM major is not an event, but a process based on a collection of curricular, instructional, and cultural issues."[26] Opportunity gaps interact with pedagogical, curricular, and sociocultural factors to deter students from entering STEM fields or cause students to leave those fields for non-STEM disciplines.

Yet research into the sources of STEM equity gaps also suggests that there is significant space for colleges and universities to improve STEM retention among female and URM students. Institutions of higher education can mitigate gaps in preparation by changing pedagogy and curricula and by addressing the sociocultural forces that inhibit persistence. They can also provide underrepresented students with supportive communities, help

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Angela Johnson, "Understanding the Science Experience of Successful Women of Color: Science Identity as an Analytic Lens," *Journal of Research in Science Teaching* 44(8) (October 2007): 1187-1218.

[23] Mica Estrada, et al., "Improving Underrepresented Minority Student Persistence in STEM," *CBE—Life Sciences Education* 15(3) (Fall 2016), p. 7. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5008901/. Ming-Te Wang and Jessica L. Degol, "Gender Gap in Science, Technology, Engineering, and Mathematics (STEM): Current Knowledge, Implications for Practice, Policy, and Future Directions," *Educational Psychology Review* 29, no 1 (March 2017): 119-140. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5404748/.

[24] Linda Sax, "Expanding the Pipeline: Characteristics of Male and Female Prospective Computer Science Majors – Examining Four Decades of Changes," *Computing Research News* 29, no 2 (February 2017), https://cra.org/crn/2017/02/prospective-cs-majors-4-decades-of-change/.

[25] K.D. Gibbs and K.A. Griffin, "What Do I Want To Be with my PhD? The Role of Personal Values and Structural Dynamics in Shaping the Career Interests of Recent Biomedical Science PhD Graduates," *CBE Life Science Education* 12, no. 4 (Winter 2013), https://www.ncbi.nlm.nih.gov/pubmed/24297297; Dustin B. Thoman, et al., "The Role of Altruistic Values in Motivating Underrepresented Minority Students for Biomedicine," *Bioscience* 65, no. 2 (2015), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4731875/.

[26] Jessica Ellis, Bailey K. Fosdick, and Chris Rasmussen, "Women 1.5 Times More Likely to Leave STEM Pipeline after Calculus Compared to Men: Lack of Mathematical Confidence a Potential Culprit," *PLoS One* 11 (Summer 2016), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4943602/.

those students better identify with the discipline that they are studying, and reshape pedagogy and curricula in ways that engage students more fully and improve learning outcomes.[27]

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[27] Mitchell J. Chang, et al., "What Matters in College for Retaining Aspiring Scientists and Engineers from Underrepresented Racial Groups," *Journal of Research in Science Teaching* 51, no. 5 (2014), pp. 570-2.