California Education Learning Lab

Addressing STEM Enrollment, Completion, and Performance Gaps in Higher Education

September 2019

This brief examines approaches to mitigating and closing STEM enrollment, completion, and performance gaps. It discusses strategies and initiatives that institutions of higher education have implemented to reduce those gaps and the relationship between programs to close equity gaps and efforts to improve STEM pedagogy and curricula more broadly. It also considers how technological change impacts efforts to change the STEM undergraduate learning experience and how new technological tools can support student learning and pedagogical innovation.

Researchers have identified a number of factors that contribute to high rates of attrition among female and underrepresented minority (URM) students from STEM fields. First, opportunity gaps in K-12 education disproportionately leave underrepresented students less well prepared for college-level STEM courses. Second, traditional pedagogical and curricular approaches, particularly a reliance on large, lecture-based introductory "gateway" courses, drive previously eager students out of STEM and into other fields. The impact of such courses, which often feature instruction targeted towards the students with the best incoming preparation and uninspiring pedagogical practices, falls disproportionately on underrepresented students. Third, sociocultural factors (including social stereotypes) deter URM and female students from entering STEM fields and magnify the negative aspects of gateway courses. The classroom and disciplinary culture of STEM departments further leaves URM and female students feeling unwelcome and unsupported in those fields.

Significantly, research indicates that well-constructed programs of student support and of pedagogical and curricular change can mitigate the impact of both opportunity gaps and of sociocultural barriers. "[C]olleges and universities can make a significant difference in reducing racial disparities in science achievement and do not have to wait idly for high schools to send them more well-prepared students."[1] Institutions of higher education and STEM departments have created and expanded a number of programs that provide cultural and academic support to underrepresented students, and have also taken steps and implemented programs to improve or modify pedagogy and curriculum.

In the last two decades, efforts to address high rates of attrition in STEM fields have generally taken one of two forms:

- Institutions of higher education and STEM departments have created a range of programs to reduce cultural barriers and provide academic and community support for underrepresented students. The specific form and reach of these initiatives can differ substantially among institutions, but the goal of these supportive programs is generally to create inclusive learning communities among participants, to

[1] 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. 571.

provide social and academic support, and to encourage academic practices that help underrepresented students identify with the discipline they are studying.

- Institutions, individual faculty members, and educational and science associations have also worked to transform STEM pedagogy and curricula. STEM associations and education researchers have raised awareness of research into the science of learning and sought to incorporate the findings from the science of learning and discipline-based education research in their pedagogy. In so doing, they have sought to improve all aspects of student performance, including reducing attrition. A range of initiatives and efforts further aim to encourage faculty to move away from traditional lecture- and testing-based instruction and to adopt evidence-based instruction, including the use of active learning approaches that aim to increase student engagement and attainment.

Education researchers observe, however, that efforts to address STEM equity gaps have generally proceeded separately from parallel initiatives to improve STEM pedagogy and curricula more broadly. This lack of integration between programs that are oriented, on the one hand, toward providing cultural support for underrepresented students and, on the other, toward reforming STEM pedagogy and curricula has tended to limit the full impact of both these approaches.[2]

Meanwhile, the expansion of online and hybrid education and the emergence of a diverse range of educational technologies and technology enhanced learning platforms have added a new dimension to efforts to close STEM equity gaps. Institutions of higher education and higher education associations have proposed adaptive learning platforms as a tool for facilitating more personalized learning experiences at scale.[3] Education researchers also emphasize the potential of adaptive technologies to provide instructors with better assessments of students' learning and to support data-driven processes of pedagogical improvement.

Addressing STEM equity gaps requires integrating approaches to improving student-learning outcomes that have generally remained separate and distinct. This means addressing cultural and pedagogical sources of equity gaps simultaneously by encouraging faculty and departments to reshape traditional pedagogy and curricula at the same time as they seek to change traditional disciplinary cultures. It also means confronting the changing technological contexts within which students learn by developing effective strategies for incorporating educational technologies that support better learning outcomes for all students, especially those who have been historically underrepresented in STEM.

---

[2] Mica Estrada, et al., "Improving Underrepresented Minority Student Persistence in STEM," *CBE—Life Sciences Education* 15(3) (Fall 2016), pp. 5-6. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5008901/; 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. 7. Retrieved from: https://pullias.usc.edu/csustemcollab/#report.

[3] Achieving the Dream, "New National Effort Aims to Dramatically Increase Number of Colleges & Universities Implementing Adaptive Courseware to Boost Retention & Graduation Levels," (Press Release, February 20, 2019), https://www.achievingthedream.org/press_release/17630/new-national-effort-aims-to-dramatically-increase-number-of-colleges-universities-implementing-adaptive-courseware-to-boost-retention-graduation-levels. Ashley A. Smith, "Next on College Completion Agenda: Equity," *Inside HigherEd* (February 25, 2019), https://www.insidehighered.com/news/2019/02/25/community-colleges-focus-equity-next-piece-completion-agenda.

Academic and Cultural Support Programs

In order to address high rates of female and URM student attrition from STEM fields, institutions of higher education have created programs and initiatives that aim to improve academic success for underrepresented students by addressing the sociocultural sources of enrollment and persistence gaps. These programs provide academic and social support for underrepresented students. They also aim to mitigate the impact of cultural stereotypes and disciplinary cultures that deter students from remaining in STEM by cultivating and encouraging students' identification with science and with their chosen STEM field. To these ends, supportive programs may sponsor summer bridge programs that help students adjust academically and culturally to higher education, create learning communities, provide academic support in gateway courses, encourage students to engage with faculty and potential career mentors, and encourage undergraduate research opportunities that make students members of research groups.

A substantial body of research supports the effectiveness of programs that provide underrepresented students with cultural and academic support and that encourage them to feel that they are part of the STEM fields they are studying. "[P]rogram interventions that support and develop students' science efficacy, identity, motivation, and values have been found to promote persistence."[4] In particular, studies suggest a correlation between URM students' persistence in STEM and their participation in a club or organization related to their major or engagement in research projects that encourage them to identify with their field of study. One study found that URM students who participated in undergraduate research programs were 17 percent more likely to persist in STEM than students who did not participate in such programs; URM students who joined clubs related to their major were 9 percent more likely to remain in STEM.[5]

There are a number of well-established programs nationally and in California that have demonstrated success in serving underrepresented STEM students and have promoted improved student outcomes by effectively implementing these supportive strategies and practices. Within California's institutions of higher education, projects to support underrepresented students include broad intersegmental and system-wide initiatives, as well as programs that are campus and discipline specific. Examples include:

- The UCLA Program for Excellence in Education and Research in the Sciences (PEERS), which was founded in 2003 and addresses challenges of persistence among life and physical science majors from underrepresented backgrounds. PEERS provides seminars, collaborative learning workshops, personalized academic advising, research talks with faculty, and opportunities to pursue undergraduate research in order to provide community and support for students and enhance their educational experience. A review of the PEERS program's influence on student trajectories found that about 90 percent of program participants remained in science majors after two years, compared to 70 percent of students in a control group.[6]

---

[4] Mica Estrada, et al., "Improving Underrepresented Minority Student Persistence in STEM," *CBE—Life Sciences Education* 15(3) (Fall 2016), p. 5. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5008901/.

[5] 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.

[6] Brit Toven-Lindsey, et al., "Increasing Persistence in Undergraduate Science Majors: A Model for Institutional Support of Underrepresented Students," *CBE—Life Sciences Education* (Vol 14, Summer 2015).

- UC Berkeley's Biology Scholars Program (BSP), which was founded in 1992, aims to make life sciences more accessible to underrepresented students. BSP provides academic support, seminar series, advising and mentoring, access to student research opportunities, and a learning community. It also aims to provide holistic support and to address the impact that personal, family, or financial issues might have on students' performance. Its participants are mostly URM, female, and from low-income backgrounds and, although they enter with high school GPAs and SAT scores that are lower than non-participants, they show rates of retention and persistence comparable to those of high-achieving students.[7]
- The CSU Louis Stokes Alliance for Minority Participation (LSAMP). LSAMP programs differ among CSU campuses, but common practices include supporting STEM summer bridge programs, providing academic support in gateway courses, and facilitating research opportunities for participants. CSU students who participate in LSAMP are 1.2-to-1.8 times more likely to remain in STEM than non-participants.[8]
- The CSU STEM Collaboratives Project provided eight CSU campuses with the opportunity to integrate high-impact practices to support first-year STEM students. The initiatives combined curricular changes that included summer bridge programs and redesigned introductory STEM courses with systematic support interventions that provided advising, learning communities, undergraduate and service-learning opportunities, and supplemental instruction.[9]
- The Math, Engineering, Science Achievement (MESA) Community College Program is a joint UC and community college effort to support community college students intending to transfer into a STEM field. The MESA Community College Program includes centers at 40 California community colleges. These centers provide counseling and orientation services for students, create peer learning communities, and support career development opportunities.[10]

Academic and community support programs have contributed to significant gains in retention and completion for their participants and underscore the potential for academic and social support to reduce equity gaps in STEM. Yet researchers and faculty also observe that support programs have limitations. Existing programs supporting underrepresented students in STEM often adopt a targeted approach to the students they serve and may aim to support relatively small numbers of students who already have a high level of interest in STEM. Some CSU LSAMP programs, for instance, focus on encouraging students to pursue graduate studies. In addition, these programs have tended to be "isolated from the overall campus," and have focused on providing individualized support for students rather than addressing institutional-level barriers to student

[7] Biology Scholars Program. https://bsp.berkeley.edu/home. John Matsui, Roger Liu, and Caroline M. Kane, "Evaluating a Science Diversity Program at UC Berkeley: More Questions than Answers," *Cell Biology Education* 2 (Summer 2003): 117-121, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC162187/; John Matsui, "'Outsiders at the Table'—Diversity Lessons from the Biology Scholars Program at the University of California, Berkeley," *CBE Life Science Education* 17, no 3 (Fall 2018), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6234806/.

[8] Lisa Hammersley, *2015 Impact Report* (California State University, Sacramento, 2015), https://www.csus.edu/csu-lsamp/CSULSAMP%20Impact%202015(small).pdf.

[9] 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), pp. 12, 25. Retrieved from: https://pullias.usc.edu/csustemcollab/#report.

[10] MESA, MESA Community College Program, https://mesa.ucop.edu/program/mesa-community-college-program/.

success, including pedagogical and curricular barriers.[11] Researchers and STEM educators suggest that addressing equity gaps in STEM more broadly will require integrated approaches that simultaneously provide cultural support and reshape pedagogy and curricula.

Pedagogy

Traditional practices in STEM pedagogy and curricula are an additional source of high rates of student attrition in STEM fields overall and of low rates of persistence and completion among female and URM students. Students entering STEM higher education face sequences of demanding gateway courses that are customarily lecture based, leaving students to absorb passively substantial quantities of abstract and technical information. Students often report that they find such courses to be uninteresting and uninspiring. These gateway courses are, moreover, often graded on curves, creating a competitive environment among students. Research suggests that these traditional practices, which have a negative effect on most students, have a disproportionately harmful impact on URM and female students.

Science of learning and discipline-based education research suggests that alternative pedagogical approaches can produce significant improvements in student learning outcomes. "Research has established that people do not develop true understanding of a complex subject such as science by listening passively to explanations." Instead, students establish true understanding through "effortful study," by actively building on their own thinking and knowledge, and by learning to "evaluate and correct their own understanding and thinking processes."[12] STEM organizations and researchers recommend that faculty adopt pedagogical strategies and practices that draw from the science of learning and that encourage students to engage actively with course content and with the learning process. In the last decade, a number of educational and scientific organizations, including the National Science Foundation, the National Academies of Science and Engineering, and the Association of American Universities have called for the adoption of these more effective teaching methods.[13]

Significantly, leading experts in education research further encourage faculty and departments to implement active learning and other innovative pedagogical practices in an iterative fashion. This includes developing pedagogy and curricular approaches on the bases of systematic collection and analysis of student learning data. The goal is to create a data-driven process of pedagogical improvement and a virtuous cycle of research and implementation.[14]

---

[11] 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; Mica Estrada, et al., "Improving Underrepresented Minority Student Persistence in STEM," *CBE—Life Sciences Education* 15(3) (Fall 2016), p. 6. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5008901/.

[12] Carl Wieman, *Improving How Universities Teach Science: Lessons from the Science Education Initiative* (Cambridge, MA: Harvard University Press, 2017), pp. 9-10.

[13] 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, CD: National Academies, Press, 2012); Association of American Universities, Undergraduate STEM Education Initiative, https://www.aau.edu/education-community-impact/undergraduate-education/undergraduate-stem-education-initiative-3.

[14] Carl Wieman, *Improving How Universities Teach Science: Lessons from the Science Education Initiative* (Cambridge, MA: Harvard University Press, 2017).

Institutions and faculty have adopted a variety of active learning strategies to encourage greater attainment and engagement from students.[15] Active learning strategies can take various forms and can integrate a variety of different practices, including:

- "Flipping" the class, wherein the student prepares before class through readings, pre-recorded video lectures, or online modules and class time is spent on active and collaborative learning activities.
- The use of personal response systems, or "clickers," that allow students to interact with faculty and to signal to the instructor whether students have understood concepts covered in class.
- The use of collaborative and cooperative learning, often oriented towards applying course concepts to solving real-world problems, with the goal of encouraging student engagement and conceptual understanding.
- The creation of opportunities for undergraduates (including freshmen) to undertake or participate in research projects, including innovative large-scale course-based research projects, in order to enhance student engagement and provide opportunities for hands-on learning.[16]

Research studies support the efficacy of active learning and its potential to enhance both student learning and the student learning experience. A 2014 meta-study published in the *Proceedings of the National Academy of Sciences* reviewed 225 studies and found that students consistently performed better in STEM courses that employed active learning compared to traditional lecturing. Notably, students in courses under traditional lecturing were 1.5 times more likely to fail than in courses using active learning.[17]

The application of active learning approaches appears, moreover, to carry particular benefits for female and URM students. The lecture-based environment of traditional STEM gateway courses can be particularly challenging for underrepresented students who already confront challenges of social isolation as a result of the lack of diversity in STEM fields and may have lower confidence than peers who benefit from greater social advantages. Conversely, researchers find that active learning can encourage student self-confidence and feelings of belonging; one study concluded, "[a]n active classroom using structured group activities also resulted in increased self-reported student confidence in scientific ability and overall increased classroom social belonging."[18] Researchers find that group activities can enhance URM students' feelings of belonging, while an emphasis on low-risk assessments and group work helps to increase student confidence and provides a foundation for greater attainment and better learning outcomes.

Barriers to Pedagogical Change

Despite extensive research into the science of learning and into discipline-based education research, and considerable evidence that illustrates the advantages of active learning, there is often a substantial gap

[15] Tim Stephens, "Active Learning Movement Gains Momentum," UC Santa Cruz Newscenter (January 20, 2016), https://news.ucsc.edu/2016/01/active-learning.html.

[16] 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/.

[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.

[18] Cissy J. Ballen, et al. "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.

between learning science research and actual practices in the college classroom. "There is a striking disconnect between the impressive extent of discipline-based research that argues for new approaches to classroom teaching, and the depressingly low rates of adoption of these new ideas."[19] Faculty members are often unaware of developments in discipline-specific pedagogical developments or reluctant to change their approach to teaching. Moreover, when faculty and instructors are interested in redesigning courses and applying new pedagogical approaches, they may receive limited departmental or institutional guidance or support in integrating the results of learning science research into their own courses and pedagogy.

A range of institutional and disciplinary barriers can impede the adoption and successful implementation of demonstrated pedagogical approaches. Creating broad-based and enduring improvements in pedagogy and curricula requires both departmental support and faculty coordination and collaboration. Academic departments, however, have traditionally granted faculty considerable autonomy in how they approach teaching and how they organize their courses. Encouraging systematic pedagogical change can run into resistance from faculty members who may be reluctant to adopt approaches to teaching that differ substantially from what they encountered as a student and depart from their own conceptions of what constitutes good teaching and effective pedagogy.[20] Moreover, although researchers encourage an approach to pedagogical innovation that includes data-based iteration, relatively few departments take a systematic approach to the collection and evaluation of data relating to student learning. Part of the reason for this is the lack of technology for making such data collection and evaluation easy to do.

Meanwhile, departmental and disciplinary cultures at 4-year universities often prioritize research over teaching. At most institutions of higher education and in most departments "[t]here is nothing in the formal incentive structure that encourages the adoption of better teaching methods by individuals, or in fact even recognizes that there are different teaching methods that might be used."[21] Tenure and promotion guidelines, especially at research-intensive universities, emphasize faculty research, not effective teaching. Departments rarely incentivize faculty to adopt pedagogical approaches that promise to improve student learning. Instead, faculty seek out to improve their teaching because they find it personally rewarding. Yet the process of re-designing courses and developing expertise in new pedagogical approaches is time intensive. Faculty members explain that a primary key reason for not incorporating active learning into their courses lies in lack of time, opportunity, or support to redesign their courses or train in new teaching approaches.[22]

Improving student-learning outcomes thus means both addressing institutional barriers to pedagogical and curricular change and finding ways to incentivize and enable both academic departments and faculty to adopt

---

[19] Robert N. Shelton and G. Peter Lepage, "Introduction," in Erin L. Dolan, et al., *Improving Undergraduate STEM Education at Research Universities: a Collection of Case Studies* (Tucson, AZ: Research Corporation for Science Advancement, 2016), p. vii. https://www.aau.edu/sites/default/files/STEM%20Scholarship/RCSA2016.pdf.
[20] Joel Smith and Lauren Herckis, *Understanding and Overcoming Institutional Roadblocks to the Adoption and Use of Technology-Enhanced Learning Resources in Higher Education* (Carnegie Mellon University, The Simon Initiative, June 2018), p. 27, https://www.cmu.edu/simon/news/docs/ccny-report.pdf.
[21] Carl Wieman, *Improving How Universities Teach Science: Lessons from the Science Education Initiative* (Cambridge, MA: Harvard University Press, 2017), p. 138.
[22] Beth McMurtrie, "Many Professors Want to Change Their Teaching but Don't. One University Found out Why," *Chronicle of Higher Education* (March 21, 2019), https://www.chronicle.com/article/Many-Professors-Want-to-Change/245945.

best pedagogical practices. This includes encouraging departments and faculty to undertake sustained efforts to promote and support pedagogical improvement. It also includes realigning institutional incentives to better prioritize and support effective pedagogy. In addition, promoting wide-scale pedagogical and curricular improvements entails supporting faculty professional development. Although active learning strategies can be very effective in improving student engagement and learning outcomes, faculty also require preparation and training to make full and effective use of these strategies.[23]

The Role of Technology in Addressing Equity Gaps

Educational technologies offer an additional tool for improving undergraduate STEM education. "The enormous increase in the capabilities of and access to information technology provide obvious opportunities for dramatically changing how teaching is done in colleges and universities and, in the process, making higher education far more effective and more efficient."[24] Some studies have suggested that courses employing technology enhanced learning can improve learning outcomes compared to traditional courses.[25] Yet, overall, the "vast opportunities" presented by educational technologies "remain largely untapped" and the impact of such technology has often been limited, "in part because its design and use are not adequately guided by good pedagogy."[26]

A great range of information and educational technologies are now available to educators. Indeed, technology has already substantially transformed students' classroom and learning experiences. Apart from the general growth of enrollment in online courses, blended classes that incorporate online interfaces and content with varying amounts of face-to-face pedagogy have become increasingly common. The practice of flipping courses to promote active learning is often made possible with the aid of educational technologies, since instructors move course material to digital media and ask students to engage with course material on-line, as well as in the classroom. Many faculty have had success using personal response systems ("clickers") to gauge student understanding in lecture-style courses and encourage student engagement and participation.[27]

Adaptive learning technology, meanwhile, has generated considerable interest and excitement by promising to provide more personalized learning to students at scale in both hybrid and online learning environments. Adaptive learning technology uses algorithms to monitor activity and mastery and to adapt content and feedback. By adapting to students' particular level of understanding and attainment and modifying content accordingly, adaptive courseware has the potential of personalizing the learning experience and improving

---

[23] 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/.

[24] Carl Wieman, *Improving How Universities Teach Science: Lessons from the Science Education Initiative* (Cambridge, MA: Harvard University Press, 2017), p. 10.

[25] Examples cited in Tyton Partners, *Learning to Adapt: A Case for Accelerating Adaptive Learning in Higher Education* (April 2013), http://tytonpartners.com/library/accelerating-adaptive-learning-in-higher-education/.

[26] Carl Wieman, *Improving How Universities Teach Science: Lessons from the Science Education Initiative* (Cambridge, MA: Harvard University Press, 2017), p. 10.

[27] 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/; Cissy J. Ballen, et al. "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.

learning outcomes. This potential of adaptive learning courseware to provide more individually targeted learning is particularly significant in the context of the growing popularity of online education and of increasing enrollment in online courses.[28]

Notable studies and trials have suggested that the use of adaptive learning technology as part of well-designed courses can produce improvements in learning outcomes, for both male and female students and across student demographic groups.[29] Other studies have found little to no improvements in student achievement using adaptive learning platforms compared to traditional, face-to-face classes, but also concluded that the efficacy of adaptive learning technology varies considerably with how it is employed.[30] A recent evaluation concluded, "[m]ore research needs to be done to assess how new uses of technology can improve student outcomes while also supporting faculty's needs."[31]

Both the CSU and UC systems have implemented programs to encourage the effective integration of education technologies into classrooms:

- In the case of CSU, the Course Redesign with Technology program was developed to identify technology-supported solutions to enrollment bottlenecks. This program has supported faculty, including STEM faculty, who have redesigned their courses to take advantage of different forms of education technology. Faculty taking part in this program have often flipped their classes and some have incorporated adaptive learning programs into their courses. This program has identified a number of redesigned STEM courses as proven examples and as models from which faculty may borrow or draw inspiration.[32]
- A 2015-16 UC pilot program evaluated the use of adaptive learning technologies in developmental calculus and chemistry courses at three campuses -- UC Davis, UC Santa Barbara, and UC Santa Cruz. This program found that the use of an adaptive learning platform appeared to contribute to moderate improvements in learning outcomes for some students. This pilot was based, however, on the introduction of adaptive learning technology without undertaking broader pedagogical or course changes to maximize the potential impact of the technology.[33]

---

[28] Catharine Bond Hill, Kevin M. Guthrie, and Martin Kurzweil, *Technology in Higher Education: Reflections from the Bowen Colloquium on Higher Education Leadership* (Ithaka S+R, February 28, 2018), https://sr.ithaka.org/wp-content/uploads/2018/02/SR-Report-Bowen-Colloquium-Technology-02282018.pdf.

[29] Examples cited in Tyton Partners, *Learning to Adapt: A Case for Accelerating Adaptive Learning in Higher Education* (April 2013), http://tytonpartners.com/library/accelerating-adaptive-learning-in-higher-education/.

[30] Louise Yarnall, Barbara Means and Tallie Wetzel, *Lessons Learned from Early Implementations of Adaptive Courseware* (SRI Education, April 2017). https://www.sri.com/sites/default/files/brochures/almap_final_report.pdf.

[31] Catharine Bond Hill, Kevin M. Guthrie, and Martin Kurzweil, *Technology in Higher Education: Reflections from the Bowen Colloquium on Higher Education Leadership* (Ithaka S+R, February 28, 2018), p. 5, https://sr.ithaka.org/wp-content/uploads/2018/02/SR-Report-Bowen-Colloquium-Technology-02282018.pdf.

[32] The California State University, Course Redesign with Technology, http://courseredesign.csuprojects.org/wp/.

[33] University of California, *Adaptive Learning Technology Pilot Report* (December 2016). Retrieved from: https://ucop.edu/institutional-research-academic-planning/_files/BFI-Adaptive-Learning-Technology-Report.pdf.

Nationally, some colleges and universities that have made large-scale efforts to integrate adaptive learning into courses report that some courses have seen significant improvements in learning outcomes, including for underrepresented students.[34]

Successful adoption of adapted learning technologies appears to rest, in part, on the development of effective strategies for the incorporation of these technologies into the classroom. Platform design plays, of course, a large role in the success of adaptive learning technologies—poor design can greatly limit instructional capabilities and success. At the same time, and with regard to well-designed platforms analyses of the use of adaptive learning and other educational technologies observe, "learning efficacy is not a trait of a product per se or simply a matter of matching the right product to the right subject matter."[35] Instead, learning outcomes are also a function of how the technology is used and how the instructor incorporates it into the class structure. The impact of adaptive learning technologies appears greatest when instructors use the data generated by the technology to identify and address the concepts with which students are struggling, and when instructors use the technology in conjuncture with and in support of broader course redesign.

In this respect, adaptive learning technology appears also to be a valuable tool for supporting data-driven pedagogical improvement. Programs like the Online Learning Initiative at Carnegie Mellon have sought to develop strategies "to use learning theory and technology to design effective instructional environments" and have explored "how to blend multiple resources such as computers, human experts and networks of peers to provide effective instruction." Such approaches employ student-learning data to create a "virtuous cycle of research and practice" by encouraging instructors to respond and adapt iteratively to student learning.[36] By offering robust opportunities to collect and analyze student-learning data, adaptive learning platforms can support iterative improvement in teaching while also providing students a more personalized learning experience.[37]

Conclusion

In the past decade, educators and institutions of higher education have implemented a range of programs, initiatives, and innovations with the aim of improving and expanding undergraduate STEM education. Research suggests that the changes needed to improve STEM learning outcomes benefit all students, while carrying particular benefit for underrepresented students.[38] Various approaches to increasing URM and female

---

[34] Karen Vignare, *Why is Launching Adaptive Learning Important* (APLU Personalized Learning Consortium, January 22, 2018), https://teaching.uncc.edu/sites/teaching.uncc.edu/files/media/20180122%20APLU-PLC%20-%20UNC%20Charlotte.pdf.

[35] Louise Yarnall, Barbara Means and Tallie Wetzel, *Lessons Learned from Early Implementations of Adaptive Courseware* (SRI Education, April 2017), p. v, https://www.sri.com/sites/default/files/brochures/almap_final_report.pdf.

[36] Candace Thille, "How Technology is Transforming Higher Education," in *Proceedings of the Aspen Institute Congressional Program—Challenges Facing America's Higher Education System* (Palo Alto, CA, October 4-7, 2013), https://assets.aspeninstitute.org/content/uploads/files/content/upload/2013_Education-Stanford-Cancelled-Notebook.pdf.

[37] Candace Thille, "How Technology is Transforming Higher Education," in *Proceedings of the Aspen Institute Congressional Program—Challenges Facing America's Higher Education System* (Palo Alto, CA, October 4-7, 2013), https://assets.aspeninstitute.org/content/uploads/files/content/upload/2013_Education-Stanford-Cancelled-Notebook.pdf.

[38] 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.

retention and progression in STEM, meanwhile, have showed positive results. In the context of ongoing efforts of STEM departments and institutions of higher education to address equity gaps, educational technologies can further facilitate improved learning outcomes when used as part of pedagogical strategies that encourage active learning and student engagement with the course and with course content, and promise to be an integral part of strategies to improve learning outcomes for all students, including those who are traditionally underrepresented in STEM fields.

Yet researchers also emphasize that closing equity gaps will ultimately require wider institutional change, including integrating cultural and academic support with broad-based and sustained pedagogical and curricular improvements. Researchers and practitioners observe that increasing female and URM representation in STEM ultimately requires "changing the way schools do business versus 'fixing the student'."[39] A primary barrier to improving learning outcomes and student learning experiences, as well as to closing equity gaps, is that the current incentive system offers little reward to institutions, departments, or individual faculty for implementing necessary changes.

Acknowledgments

Learning Lab would like to thank Carl Wieman and the other members of the Learning Lab's Advisory Committee for their input, advice, and helpful suggestions in the research and writing of this brief.

[39] John Matsui, "'Outsiders at the Table'—Diversity Lessons from the Biology Scholars Program at the University of California, Berkeley," *CBE Life Science Education* 17, no 3 (Fall 2018), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6234806/.