

DIVERSITY

Achieving STEM diversity: Fix the classrooms

Outdated teaching methods amount to discrimination

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Achieving equity in science, technology, engineering, and mathematics (STEM) requires attracting and retaining college students from diverse backgrounds. Despite decades of calls for action, change has been slow. Recommendations have largely focused on members of underrepresented groups themselves (1) rather than on fixing the classrooms that drive many students out of STEM. Without removing such barriers, funding and programs directed toward underrepresented groups will not transform STEM. Instead, we must fix the classrooms where many students from historically excluded communities (HECs) are discouraged from pursuing STEM. Here, we outline areas that need change and identify steps that can be taken by instructors, academic leadership, and government agencies to drive change at scale (see the table). Research points to active learning practices, welcoming classrooms, and content that is relevant to members of HECs as especially worthy of attention. Such evidence-based classroom practices can benefit all STEM students regardless of their background.

In the United States, more than half of the approximately 600,000 students who state their intent to major in STEM when they start college switch to other fields before they graduate (2). It is unlikely that these students leave STEM solely because of financial duress given that they have the resources to complete college. Rather, they are discouraged and often alienated by the climate and teaching methods commonly found in STEM classrooms (2). The exodus of students who are people from HECs is disturbingly high: Among those entering college intending to major in a STEM field, 42, 58, and 66% of white, Latinx, and Black students, respectively, switch to other majors. These data are particularly troubling in comparison to the humanities, social sciences, and business in which students from HECs are no more likely to switch majors than white students (3).

As we describe below, many practices that help retain students from HECs provide them with opportunities to develop a scientific identity and learn that people who look like them can succeed in STEM.

TEACHING PRACTICES

In extensive interviews of college students enrolled in STEM majors, 90% complained about poor teaching methods (2). Teaching by lecturing alone dominates introductory

STEM courses but is far less effective than active learning, especially for members of HECs (4). Active learning methods seek to engage learners and deepen understanding by emphasizing in-class discussions, practicing inquiry and problem-solving, using interactive technologies, and having students pose original ideas. Active practices can improve knowledge retention and bolster students' self-efficacy and analytical skills, providing benefits for all. Even simple changes to classroom practice can substantially improve learning in classes of all sizes. For example, brief pauses in lecture during which students discuss material with each other can increase knowledge retention immediately after the lecture and 2 weeks later (5). Active learning can close racial achievement gaps (4) and increase persistence for students from HECs (6). Accordingly, the continued exclusive use of lectures is malpractice at best, or an act of discrimination at worst.

Engaging in research is the ultimate form of active learning and enhances student retention in STEM, but students from HECs have less access to participation in faculty research (7). Course-based undergraduate research experiences (CUREs) are a form of active learning that offers a scalable way for all students to obtain research experience early in college, thereby leveling the playing field and closing the gap for students from HECs. In a typical CURE, all students in the class work on related research problems that require a limited suite of laboratory or computational methods while providing students an authentic opportunity for creativity and original thinking by having them choose a scientific question and design experiments or analyses within that framework. For example, in the SEA-PHAGES CURE, students isolate and characterize their own bacteriophages from soil; one of these phages has entered clinical trials for treatment of infectious disease. In the Genomics

Actions to create inclusive STEM college classrooms

PRINCIPLE	EXAMPLES	NATIONAL INITIATIVES	ACADEMIC LEADERSHIP	INSTRUCTORS
Overall actions		Funding agencies and institutional rating services require evidence of STEM inclusivity.	Advocate for inclusive classroom practices.	Adopt inclusive classroom practices.
Reform teaching practices	Active learning in lecture courses	Federal and private funding agencies support workshops and communities of practice to expand instructor training.	Provide funding and time to train instructors in evidence-based teaching.	Acquire training in evidence-based teaching.
	Research courses (CUREs) for first-year students	Federal and private agencies support national projects and local initiatives to enable instructors to teach CUREs.	Provide funding to promote CUREs to potential donors, lawmakers, and local community partners.	Teach existing CUREs or develop new ones.
Create welcoming classrooms	Values affirmation, growth mindset, discussion of adversity	Require evidence of institutional practices that increase persistence of underrepresented students for eligibility for federal funding and require bias training for investigators on all grants.	Include adoption of inclusive classroom practices in evaluation for tenure, promotion, and teaching awards; incentivize instructor communities of practice for inclusive approaches.	Integrate welcoming-classroom practices into syllabus and classroom.
Expand relevance to diverse groups	Social impact of STEM and incorporation of diverse role models	Federal agencies, advertisers, and national publications spotlight diverse STEM professionals and the impact of STEM on diverse societal issues.	Spotlight diverse STEM faculty and the impact of STEM discoveries on diverse societal issues.	Include impacts of STEM on society and diverse role models in course content and public art.



A mural at the Wisconsin Institute for Discovery, University of Wisconsin–Madison, USA, depicts diversity in science.

Education Partnership, students analyze and annotate genetic material that has not been examined previously, and in *Tiny Earth*, students isolate antibiotic-producing bacteria and characterize the bacteria and the compounds they produce [see supplementary materials (SM)]. The structured nature of CUREs, coupled with a defined range of techniques, makes it feasible for an instructor to provide a research experience with opportunity for real discovery for 25 students during the semester. The independence and originality of their research build students' identities as scientists, as they are scientists for a term. CUREs improve retention of students in STEM majors (8) and are unlike any other teaching method—just one well-run CURE taken early in college increases student persistence (9, 10). CUREs offer all students an opportunity to be scientists, and unlike typical introductory laboratory courses, enable students to take intellectual ownership of their projects, a critical step in identifying as a scientist. Working in a community of peers that is more likely than instructors to be populated with people from HECs also reinforces that people who look like them can succeed in science.

WELCOMING CLASSROOMS

Students cite the “weed-out mentality,” which sends a message that instructors expect high failure rates in their large-enrollment foundational classes, as a reason for switching majors (2). STEM faculty may tout high failure rates in their classes as an indication that their discipline is rigorous and only the “best” are welcome, but science classes taught from this perspective do not select for the best. Rather, they drive away many talented students who leave simply because they feel they don't belong. The harsh, competitive climate advocated by some STEM educators may en-

courage some students to strive harder, but negatively affects and stifles growth of others who then choose to switch to more collaborative and kinder environments (11).

To address the sense of exclusion experienced by members of HECs, simple, proven interventions can make classrooms more welcoming. Teaching the “growth mindset,” or the idea that with sufficient effort, anyone can succeed, leads to better student outcomes than utilizing a “fixed mindset,” weed-out mentality. For example, an instructor telling students who performed poorly on an exam that with sufficient hard work they have the ability to improve is empowering and motivating, whereas telling them that “science isn't for everyone” or “some people have it and some don't” can strip students' confidence. A large national study of over 15,000 students showed that racially associated differences in performance were cut in half in classes taught by instructors who displayed a growth mindset (12).

Having students write briefly about what matters to them boosts performance, presumably by validating their values and sending the message that they belong. Providing students with evidence that all students face adversity is a simple practice that increases student persistence. The performance, persistence, and health of students from HECs improved after reading about the experiences of more senior students navigating adversity and achieving success (13). An exercise in which students wrote about their own abilities and strengths increased performance and closed racial and gender achievement gaps. These brief interventions require only minutes yet can have substantial effects on students' academic decisions and performance even years later (see SM). More research is needed to

determine how these and other brief interventions can be customized to maximize impact for HEC students in STEM classes.

Cumulative effects of macro- and micro-aggressions amplify the unwelcoming atmosphere. These range from subtle products of unconscious bias to blatant racism and misogyny. By contrast, micro- and macro-affirmations send social cues of inclusion (11). For example, one study of 6500 faculty showed that on average, they are less likely to respond to emails that appear to be from women students or students of certain ethnic groups, which is a microaggression stemming from unconscious bias (7). Reducing discrimination by training people to become aware of their biases and to hold each other accountable for behaviors engenders fairness and can improve retention of diverse students.

CONTENT RELEVANT TO HISTORICALLY EXCLUDED COMMUNITIES

Students can be either alienated or motivated by course content. The positive impact of STEM research on human welfare can be particularly motivating for many students from HECs who rank social good as a higher priority in choosing a career than do non-HEC students. Discussing the negative impacts of research on certain ethnic groups can make students of those groups feel included. For example, an introductory chemistry course might discuss the implications of dumping uranium on Native American reservations, or a biology course could discuss the impact of breaking the genetic code on vaccine development.

Many students complete college without ever encountering instructors or examples of key scientists who are members of HECs, thereby perpetuating stereotypes and requiring students of some groups to imagine

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becoming something they have never seen. Exposure to diverse role models increases career motivation and improves academic performance by students from HECs. Even as little as a 2-minute exposure to a positive female role model increased retention of women in STEM (14).

The appearance of classrooms and the people in them creates an atmosphere that is either welcoming or alienating to members of HECs. Even in the absence of diverse instructors, being surrounded by images of diverse scientists will benefit all students. Changes in classrooms as seemingly insignificant as including simple household objects can alter the sense of belonging for members of certain groups, and imagery can change attitudes of others toward members of HECs (15). Although more research is needed to determine best practices, published findings send a strong message that combining inclusive content with diverse role models and classroom visuals can send the message that everyone belongs in science.

ACTIONS NEEDED AT ALL LEVELS

Players at every level of higher education have the power to contribute to needed changes.

Instructors

Instructors have agency over the classroom environment and can immediately implement new strategies. Help in incorporating evidence-based inclusive teaching practices should be available to all instructors. Interventions that strongly influence achievement by students from HECs include projecting an instructor's growth mindset and using writing exercises on personal values or the utility value of the subject; these are simple strategies accessible to all instructors. "Scientist Spotlights" (short reading assignments about diverse scientists who have contributed to the topic at hand) can shift stereotypic views of who is a scientist. Instructors can also leverage the inclusive benefits of a highly structured course design that makes expectations and the path to success transparent to all students. Students and instructors can collaborate to bring inclusivity into the physical environment, perhaps by seeking institutional support for public art that depicts diversity in science. Several US universities have murals and statues that provide models (see the figure).

Academic leaders

Institutional leaders need to clear the path for instructors to drive change in the classroom. Institutions need leaders who advocate for inclusive classroom methods and encourage broadening hiring, tenure, and promotion criteria to incentivize inclusive practices. Leaders should require data on demograph-

ics of students and their success and then support departments that are diversifying STEM with awards, budgets, and time. Some have solicited donors to help recognize inclusive programs or support their development, including funding course release time or sabbaticals to enable instructors to acquire expertise and revise courses. Providing teaching spaces that facilitate active learning methods, including CUREs, is critical. Academic leaders can reinforce the work of instructors by instigating discussions of discrimination in science at the campus level and modeling how to handle controversial or charged topics, while celebrating positive changes.

Campus leaders can also introduce established training programs that help instructors recognize and mitigate the effects of their own biases. To increase the diversity of role models, leaders should ensure that hiring committees are equipped with proven practices that increase the diversity of candidates, including discussing implicit bias, fully empowering all committee members to participate in the search process, enunciating the value of diversity to the institution and to the STEM community, providing candidates with evidence of a welcoming climate, and holding all accountable for outcomes. Recruitment of diverse people is not sufficient; the climate and reward system must reflect the value of retaining scholars from HECs.

National level

Funding agencies that support education reform (such as the US National Science Foundation) and policy-makers need to support substantial expansion of programs for instructors in active learning and implementation of CUREs at scale. Funding agencies can increase the visibility of diverse role models by providing financial resources to assemble a library of freely available recorded lectures or active learning experiences that feature diverse instructors on topics that can be readily incorporated into the introductory STEM curriculum. Funding agencies could also hold institutions accountable for success in diversifying STEM by requiring demographic data on persistence and graduation rates.

Organizations beyond the typical academic players also shape STEM. Program certification and college ranking services have the power to transform STEM education by incorporating the prevalence of inclusive classroom practices and instructor training into their criteria. For example, using the availability of CUREs for first-year students as a feature of college ratings would instantly draw the attention of academic leaders and funders. Institutional success in recruiting and graduating members of HECs in STEM could also be included. Several corporations have used

images of diverse scientists in their advertising, and some members of the entertainment media have raised the visibility of diverse scientists through fictional characters. Others could pick up the mantle and create a pervasive image of a diverse STEM workforce to inspire students with role models.

STOP TRYING TO "FIX" THE STUDENTS

Further research is needed to understand why certain interventions improve retention of students from HECs in STEM. For example, are there unidentified factors in CUREs that make them such a powerful tool? Is failure more acceptable to students when they observe that everyone's experiments fail some of the time and we learn from failure? Are there other practices to borrow from fields that do not suffer the high exodus of HEC student seen in STEM? What is the range of images that provide a sense of belonging to members of HECs?

Programs that provide students from HECs with financial support in the absence of institutional change place the burden of change on the students. We need to stop trying to "fix" the students and fix our classrooms instead. "The fierce urgency of now," to use the words of Martin Luther King Jr., should drive institutions to examine structural discrimination and find inclusive solutions that scale. Only through systemic change can we transform STEM education into an enterprise in which all students can succeed. ■

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