Reimagining the Pipeline: Advancing STEM Diversity, Persistence, and Success

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Achieving trainee diversity in science, technology, engineering, and mathematics is rapidly becoming a challenge faced by many nations. Success in this area ensures the availability of a workforce capable of engaging in scientific practices that will promote increased production capacity and creativity and will preserve global scientific competitiveness. The near-term vision of achieving this goal is within reach and will capitalize on the growing numbers of underrepresented minority groups in the population. Although many nations have had remarkable histories as leaders in science and technology, few have simultaneously struggled with the challenge of meeting the educational and training needs of underrepresented groups. In this article, we share strategies for building the agency of the scientific community to achieve greater diversity by highlighting four key action areas: (1) aligning institutional culture and climate; (2) building interinstitutional partnerships; (3) building and sustaining critical mass; and (4) ensuring, rewarding, and maximizing faculty involvement.

Keywords: diversity, retention, STEM education, training, workforce

Racial and ethnic population change in the United States continues to reshape the American identity and the composition of its workforce. Despite efforts over the past 30 years, only modest improvements in workforce diversity in the sciences have been achieved (Antonio 2002, Villalpando and Delgado Bernal 2002, Mervis 2005). Negative socioeconomic factors continue to account for disproportionately lower numbers of racial and ethnic minorities, such as African Americans, Hispanics, Native Americans, and Pacific Islanders in the science, technology, engineering, and mathematics (STEM) training pipeline and scientific workforce (Estrada-Hollenbeck et al. 2011). These underrepresented racial and ethnic minorities (URMs) accounted for approximately 29.4% of the US population in 2010 (see table 1-2 in NSF 2013) but accounted for only about 13.3% of employed scientists and engineers (see table 9-38 in NSF 2013). Ironically, the United States's role as a STEM field leader, along with its rapidly changing demographics, makes it uniquely qualified to address the challenges of achieving STEM field diversity that can serve as an example for other nations. The increasing challenge to the United States's leadership position in STEM disciplines functions as the driving force for improving STEM education and training outcomes (NRC 2007, 2011a). The additional benefit of developing a STEM-literate and well-trained domestic workforce is that this ensures that we adequately address challenges related to healthcare improvement, national production capacity, and research excellence (NRC 2011b).

Although the definition of underrepresented groups may change as US demographics change, underrepresented racial and ethnic groups will probably always exist, and, therefore, race and ethnic status will always matter. Accordingly, the life span of programs designed to address the needs of underrepresented trainees cannot be predicted. Increasing the representation of individuals from underrepresented groups in STEM fields is a function of pipeline flow (McGee et al. 2012), which is measured as the rate at which trainees enter and advance through the pipeline to the workforce. The STEM pipeline analogy represents the long-standing logical framework describing how trainees advance through the scientific educational and training process, with success measured by movement from the precollege levels to more advanced postgraduate levels. The ongoing challenge of achieving the desired level of STEM workforce diversity leads us to reimagine this pipeline as a vertical structure that is subject to the laws of physics, where downward forces, such as poor or insufficient mentorship, oppose the upward flow of STEM trainee progression, resulting in STEM attrition (figure 1). In this article, we present key intervention strategies that we believe will create a net upward force, to increase persistence, reduce attrition, and successfully increase diversity in the STEM pipeline and workforce.

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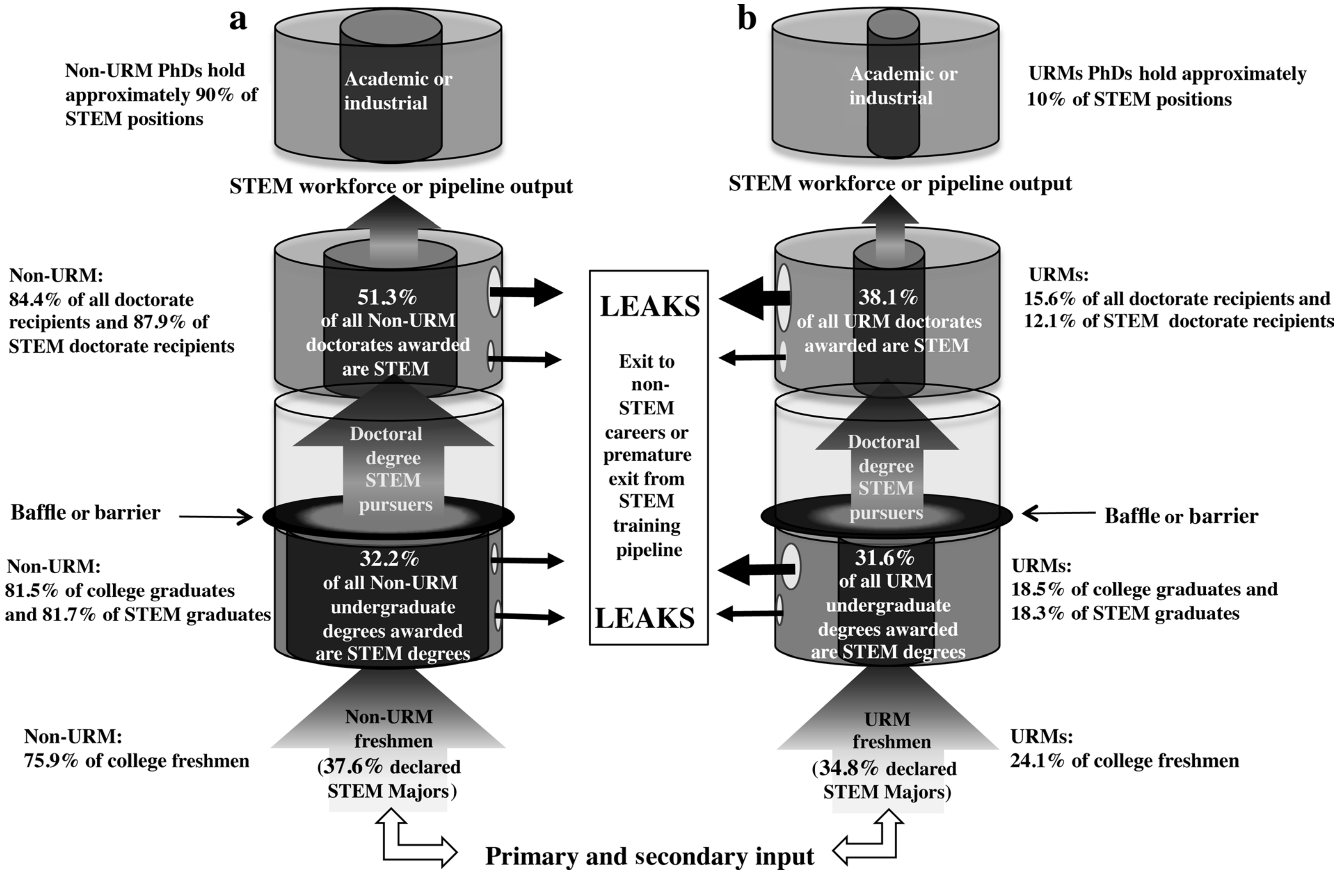

Figure 1. The reimagined science, technology, engineering, and mathematics (STEM) pipeline for US underrepresented racial and ethnic minorities (URMs) and nonminorities: the progression of non-URM and URM trainees from undergraduate to postdegree career training stages. For illustrative purposes only, the pipeline population has been divided to show the progression of non-URM and URM trainees separately. The shaded upward arrows indicate advancement through the STEM training pipeline. The baffle between the undergraduate and graduate segments of the pipeline highlights the greatest barrier to the advancement of STEM training. Gaps or discontinuities between segments illustrate that the pipeline can be discontinuous for trainees who take breaks before advancing. Leaks *represents trainee attrition.*

A 10-year (2000–2010) assessment of the STEM pipeline

It has long been recognized that the STEM pipeline is *leaky*—a term that refers to the unintended loss of trainees from the disciplines. Addressing this issue is not only vital to improving STEM field diversity and broadening participation, but it is also uniformly important in maximizing the retention and persistence of those already in the fields. Figure 1 is a visual representation of the vertical pipeline flow and persistence from 2000 to 2010. It shows that a comparable percentage of both URM and non-URM college students—34.8% and 37.6%, respectively—declared STEM majors in their first year, although URMs account for 24.1% of enrolled undergraduates and non-URMs account for 75.9% (see appendix table 2-15 in NSB 2008). An analysis of the pipeline also shows the widely known trend of early attrition for URM students, which is seen as a decrease in the percentage of URM college freshman from 24.1% in 2000 to 18.5% of college graduates in 2004, indicating a 23% attrition rate (figure 1; table B-2 in NSF 2006). An equally significant loss in URM trainees is also observed: from 18.5% of the college graduates in 2004 to 15.6% of the doctorate degree recipients in 2010 (figure 1). An assessment of science and engineering majors among this cohort indicates an even greater loss of URMs, going from 18.3% of science and engineering URM college graduates in 2004 to 12.1% of science and engineering doctorate degree recipients in 2010, which represents a 33.9% attrition rate (figure 1; table B-2 in NSF 2006).

Despite the overall loss of URM STEM trainees, the proportion of those who remained as STEM trainees at the undergraduate level is equivalent to their non-URM counterparts, at 31.6% and 32.2%, respectively (figure 1; table 5-3 in NSF 2013). However, this changes at the graduate level, at which only 38.1% of all URM doctorates awarded are STEM doctorates, whereas 51.3% of all non-URM doctorates awarded are STEM doctorates (figure 1; table 7-4 in NSF 2013). URM attrition from the field at the graduate level ultimately results in their disproportionate underrepresentation in the subsequent workforce. This is reflected in data from 2010 showing that only 10% of science and engineering postgraduate employment positions in academia, industry, and postdoctoral positions were held by URMs (figure 1; table 8-3 in NSF 2013).

The greatest barrier to STEM persistence and progression, represented by the baffle in figure 1, occurs at the undergraduate–graduate interface and reflects the need for a constant upward, opposing intervention force to maintain STEM diversity and persistence. For example, data from 2008–2009 show that 30.8% of non-URM bachelor's degree recipients went on to full-time postsecondary degree programs, 29.6% to science and engineering careers, and 29.9% to nonscience and -engineering careers. In contrast to this, only 25.7% and 27.7% of URM bachelor's degree recipients went on to full-time postsecondary degree programs and science and engineering careers, respectively, whereas 36% left the field (table 9-13 in NSF 2013).

In order to increase STEM field success, greater efforts are needed to retain trainees already in the pipeline and to change perceptions of the pipeline, itself. In particular, there is a need to reimagine the pipeline as both a structure and a process and to acknowledge that improvements in form and function are dependent on changes in human interactions and training practices.

Interventional practices to support increased STEM diversity, persistence, and success

In the United States, a growing body of literature describes efforts to address the poor representation of current underrepresented groups, particularly URMs, in the STEM workforce and the inconsistent image of STEM trainee diversity and US population diversity. Efforts to manage and support underrepresented STEM trainees require creative practices rather than the replication of past practices that have yet to achieve the desired goal of creating a diverse workforce. Some thoughtful studies, however, describe efforts to remove barriers by focusing on improving trainee performance through the creation of novel educational and training frameworks (Kelly et al. 2006, Russell et al. 2007). Others describe efforts to determine how trainees come to recognize, understand, and choose career paths and the factors that influence choice (Chemers et al. 2011, Estrada-Hollenbeck et al. 2011). These approaches all have their bases in evaluations of the rates at which trainees move through the pipeline, how and where they enter the pipeline, and when and why they prematurely exit the pipeline. STEM program development and training designed to broaden the representation and participation of the current underrepresented groups should also be designed to meet the needs of future underrepresented groups and to have a broader impact that benefits all.

Greater attention has also been paid in recent years to the structure and composition of the STEM pipeline at both the institutional and national levels (Schultz et al. 2011, McGee et al. 2012). Pipelines as physical structures require maintenance and repair, and, in some cases, parts may require replacement to preserve and enhance functionality. Such is the case for the metaphorical STEM pipeline. Although some programs and practices have met benchmarks (Junge et al. 2010, Thompson and Campbell 2013), these achievements either have not been reproduced or have been only transient. Specifically, although the outcomes of some programs show that intervention practices work, challenges clearly persist that continue to erode progress or impede the programs' sustainability. This points to the need to make repairs and improvements in the current STEM pipeline through alternative or complementing strategies that support and validate trainee identities as emerging scientists.

Social identity and a sense of belonging, regardless of race, ethnicity, gender identity, or socioeconomic status, represent powerful motives for achievement (Cohen and Garcia 2008), and, unless the foundations that validate these states are strengthened, the effectiveness and permanence of interventions that preserve our scientific workforce will be short lived. Described below are interventional practices that can support efforts to increase STEM diversity, persistence, and success by refining institutional practices; by improving support and recognition of faculty members; and by maintaining a climate that leads to meaningful, positive changes. Although the practices presented here are not a comprehensive set of action steps, incorporating them into preexisting practices may help in the implementation of changes necessary for strengthening while diversifying our domestic scientific workforce. When the underused practices that are described here are put into practice along with the current set of practices, they are likely to have transformative impacts on the movement of trainees through the pipeline. Moreover, universally incorporating them into the preexisting training modalities will yield a more uniform and comprehensive approach to constructing a more effective pipeline that leads to lasting positive changes in workforce diversity.

Aligning institutional culture and climate

Academic institutions work to make their aspirational academic environments become the actual environments that materially and nonmaterially support all members of their communities equally. Although these aspirations help establish institutional culture, it is the institutional climate that shapes the environment in which diverse scholars learn and practice. *Institutional culture* represents the collection of shared values and beliefs that is the blueprint that guides actions, which inevitably establishes climate. *Institutional climate,* however, represents the practices and behaviors that determine the prevailing attitudes in the environment. Climate affects a trainee's sense of belonging (Purdie-Vaughns et al. 2008). The alignment of climate and culture can have positive effects on participation, persistence, and success (Cress and Sax 1998). Although culture and climate should align, they often do not, and the dissonance is counterproductive (Hirt and Muffo 1998). In fact, the misalignment of culture and climate is often manifested in community members' expression of views in opposition to an institution's view of its culture and mission (Hurtado et al. 1998). STEM training programs designed to improve outcomes for underrepresented trainees do not operate in vacuums but are very much dependent on and affected by the alignment of institutional culture and climate. This alignment requires the engagement of faculty members and administrators as stakeholders who should recognize themselves as beneficiaries of investments in diversity. One mechanism for aligning climate and culture is the use of confidentially administered, annual third-party climate-assessment surveys. Data generated from these surveys can help inform and guide subsequent actions (Whittaker and Montgomery 2012, Kendricks et al. 2013), because they help monitor changes that affect the climate in which learners learn. Unlike internally developed and administered second-party institutional surveys, third-party surveys, administered by outside evaluators, maximize anonymity and response rates and can also minimize unintentional data interpretation biases.

Building interinstitutional partnerships

Faculty partnerships, especially those established between majority-serving and minority-serving institutions, represent one of the most useful but underused relationships to transform teaching and research practices that benefit underrepresented students. Such partnerships maximize interactions with and access to prospective graduate trainees and can eventually lead to relationships that enhance the social activities that help students build professional networks that can result in scientific opportunities where none existed previously (Trent et al. 2003). Interinstitutional partnerships break down the traditional barriers and training silos in which many institutions and programs operate. Those that develop as informal, faculty-driven partnerships may be particularly effective, because they work with the flexibility of research-driven collaborations, which provide reciprocally beneficial outcomes. For the research-intensive institution, they offer the opportunity to cultivate longitudinal relationships with a more diverse population of prospective graduate students. For members of minority-serving academic communities, they help promote and raise awareness regarding practices and career options available to students that might otherwise go unrecognized. For all faculty members, interinstitutional partnerships provide opportunities to share and exchange details about curricula, curricular content delivery, and pedagogy (Knisley and Behravesh 2010, Thompson and Campbell 2013). They can also be preemptive in helping identify gaps in undergraduate-student preparation before these students begin their graduate training. The ability to calibrate student readiness for graduate training is particularly important when collaborating with minority-serving institutions that lack PhD-level graduate programs and the faculty members who regularly train PhD students. For example, it is not uncommon for students deemed outstanding performers during their undergraduate years to struggle and even fail in the graduate-training environment. This is often attributable to academic gaps in their undergraduate training. The inconsistencies between successful undergraduate student performances documented in glowing reference letters and grades and the students' subsequent poor graduate performance can be preempted by building interinstitutional partnerships that allow for curricular mapping of undergraduate courses onto graduate curricular training plans. In the end, these partnerships allow for a better alignment of undergraduate and graduate curricula, thereby improving outcomes of early graduate student training. Figure 1 shows that, although 18.3% of college STEM graduates are URMs, this number drops to 12.1% who ultimately go on to earn STEM doctorates. Curricular misalignment between the undergraduate and graduate career stages is one of the factors that could account for poor advancement and outcomes in graduate training, and it is one of the contributors to the baffle in figure 1 that impedes URM progression. This misalignment is potentially more detrimental to trainees from small institutions and minority-serving institutions that lack graduate programs or access to graduate faculty.

Undergraduate students at research-intensive institutions are often more exposed to and influenced by researchers who serve as de facto role models than are students at minority-serving institutions. Accordingly, the influence of research on undergraduate education at research-intensive institutions is greater than that at minority-serving institutions. Undergraduates at research-intensive institutions are also more likely to be exposed to problem-based curricula shaped by cutting-edge research (Wiers et al. 2002, PCAST 2012) and are also more likely to complete some form of senior capstone research training (Smith 2012). If they are designed well, interinstitutional partnerships, established with underserved institutions such as minority-serving institutions, can provide increased opportunities to replicate these experiences for students at these smaller and less-well-funded institutions. Increased access to resources and opportunities is crucial to student development, and students who view their institution as having a good reputation are more likely to persist in science (Chang et al. 2008). Interinstitutional partnerships also create opportunities to establish faculty research collaborations that involve student trainees. Such collaborations help authenticate minority-serving institution faculty members' identities as scientists to their students and enhance their identities as role models (Campbell et al. 2013). Because few URM scientists currently exist at majority-serving institutions to serve as role models for students, these collaborations provide valid mentoring opportunities.

Institutional partnerships also help unmask and address cultural differences that exist as barriers to students pursuing science careers. They represent powerful vehicles for providing the context for developing cultural competency (Tanner and Allen 2007) crucial for working effectively in cross-cultural situations. The development of cultural competency in healthcare has been instrumental in narrowing health disparity gaps, and it can provide similar benefits to scientific training by raising the level of understanding of values and social practices that shape professional pursuits and professional relationships (Saha et al. 2013). For many URM students, the disadvantages of low socioeconomic status and low social status correlate with lower academic achievement and slower rates of academic progress. Partnerships can help faculty and students cultivate well-developed senses of social competency and can help them recognize when race, ethnicity, and class identity affect student academic performance.

Recent initiatives launched by the National Institutes of Health have begun to address the challenge of US scientific workforce diversity by supporting partnerships that create opportunities leading to successful science careers (*http://commonfund.nih.gov/diversity/initiatives.aspx*). These initiatives build on the early practices of the National Institute for General Medical Sciences Training's Workforce Development and Diversity Division to foster greater collaboration between institutions and programs. The availability of these new initiatives, as well as funding opportunities for individual investigators to initiate their own partnership programs, facilitates collaborations that can enhance underrepresented student participation and STEM success, especially at the graduate and postgraduate levels.

Attaining and sustaining critical mass

Achieving critical mass to ensure that underrepresented students are not isolated has been one of the strongest arguments for promoting diversity in education (*Grutter v. Bollinger*, 539 U.S. 306 [2003]). This is important, because the experience of isolation is undeniably one of the greatest challenges that underrepresented students, especially URMs, face in STEM fields (Cohen and Garcia 2008, Campbell 2013). For many students, the sense of isolation diminishes self-efficacy and resurrects stereotype threat feelings that can have a negative impact on their scientific identity (Steele 1997). Identity and self-efficacy benefit from the presence of peers to whom trainees relate best and whose presence affirms their sense of belonging (Saha et al. 2013). Although non-URM peers can serve as excellent mentors and role models for URM trainees, they alone are not sufficient to legitimize the early professional and social identities that are crucial to an early adjustment to new training environments. Not all URM trainees belong to the same socioeconomic group, and not all racial groups share the same ethnic identity, which means that not all URM students form or identify as a single cohort. Students who attended the same college, resided in a particular neighborhood, or emigrated from the same geographical region may share common experiences and, therefore, often associate early in their educational training to form support groups. This is often only a transient behavior as they adjust to new environments (Saha et al. 2013) and, unlike social-identity groups, their developed scientific identities inevitably transcend social identities. Partnerships between majority- and minority-serving institutions provide opportunities to build critical mass in the trainee graduate ranks and foster a sense of belonging to the scientific community.

Against the backdrop of the increasing STEM diversity—in the United States, for example—are the changing economic pressures of operating colleges and universities, which continue to shape institutional priorities. Many institutions have begun to address diversity by embracing both international and domestic diversity. In the United States, there are concerns that this practice may be at a cost to domestic diversity (Tapia 2007, Wilhelm 2011), with United States–trained international scientists returning to their home countries to challenge the United States's leadership in STEM fields. In spite of the potential loss of United States–trained foreign scientists, the practice of embracing both domestic and international diversity does diversify the training environment to the benefit of underrepresented US trainees. Embracing both domestic and international diversity also does not preclude the need to expand our domestic workforce. It is possible to develop inclusive practices that deliberately prioritize the needs of our domestic trainee and workforce population but that can, at the same time, accommodate the needs of others, including international trainees.

Achieving, rewarding, and maximizing faculty involvement

The inability to replicate or sustain practices that support URM student STEM participation and persistence has many root causes. One of these is the ebb and flow of progress that is linked to institutional leadership change. Advances in STEM diversity have benefited greatly from strong and committed institutional leadership, through which practices are enacted that instill a culture of inclusion and through which policies that are barriers to creating diverse learning environments and communities are eliminated (Elliot et al. 2013). Despite this commitment, the effectiveness of institutional policy change is often linked to the tenure of institutional leadership, and this creates vulnerability. The average tenure of university presidents is approximately 8.0 years (Lederman 2007), and those of provosts and medical school deans are 4.3 and 4.0 years, respectively (Lederman 2007, Fain 2010). This contrasts with the average tenure of faculty members, which is approximately 35 years (Hammond and Morgan 1991). Given their relatively short tenure, the expected life span of the work and support of high-level administrators is, at best, approximately 5–8 years. Longer institutional leadership tenures at research-intensive institutions do correlate with sustained and meaningful improvement in diversity and diversity practices (Jones 2009).

Notwithstanding the limitations on the career lengths of administrators, stronger collaborations between administrators and faculty that deepen faculty-member engagement in diversity training programs have the potential to maximize the lasting impact of these programs. Engaging faculty members to contribute to diversity programs is also consistent with an institution's and the academy's mission of allocating resources to areas of changing demands in higher education (O'Rourke 2008). Faculty members bring strong collaborative skills as investigators, and they are directly responsible for the training that produces scientists. Faculty-member-initiated research programs promote understanding in STEM fields, and their research programs receive constant and detailed attention. Because they are left relatively free to advance their scholarship, the longevity of faculty work is unaffected by institutional leadership changes. This freedom enables advances and novel, groundbreaking discoveries. STEM field diversity programs have not benefited from similar uninterrupted and compulsive attention to detail. However, it is possible that these programs, too, can achieve greater success by encouraging and supporting similar levels and degrees of freedom for faculty involvement on a scale that parallels those of research programs. STEM diversity programs are similar in many respects to investigator-initiated research programs. Both are amenable to being collaborative, quantitative, predictive, and theory-driven programs that promote change and improve understanding. Greater progress in achieving STEM diversity is possible by increasing the value and merit of STEM faculty involvement in the process. Although both faculty and administrators currently play important roles in addressing this issue, greater faculty involvement—particularly of STEM faculty—is needed and should be rewarded accordingly. Research and teaching are the only scholarly endeavors for which faculty members are customarily rewarded, which limits their involvement in other areas, in which little credit and merit is given. Faculty members should be incentivized to engage more deeply in diversity by making it a meaningful scholarly activity, alongside research and teaching. The opportunity to formally report on diversity-related activities as annual review and reward criteria for merit and promotion should be established. This practice would also begin to institutionalize diversity practices to the extent that research and teaching activities would become the mainstay of faculty-member activities.

Conclusions

It is evident that the current practices have not achieved the scientific workforce diversity sought. This failure is probably a byproduct of our perceptions of the pipeline's input, its structure, and its function. The model presented in figure 1 reimagines our understanding of the decades-old STEM pipeline. It shows that the pipeline is not self-sustaining or self-perpetuating but, rather, is dependent on thoughtful and regular input of more than trainee effort. In addition to the issues discussed here, there are a number of nuanced challenges that disproportionately affect URM trainees in the STEM pipeline. These include the challenges of managing lowered expectations and marginalization in the fields; cultural disconnects that create conflicts between graduate student life and family life; and socioeconomic status and class, which are not easily disentangled from race and ethnicity. These challenges persist presumably because the frameworks in which they can be best addressed have not been developed. Therefore, future changes in STEM training practices designed to be more inclusive must also be able to address these issues.

Successful entry into and advancement through the pipeline requires intervention strategies that are focused on reproducing not only practices that address trainee weaknesses but also those that require attention to practices that support and build strengths in other areas. Greater attention must also be focused on other input factors, which include supporting and rewarding broader faculty involvement, adapting institutional practices around goals and endpoints, and working collaboratively across institutions and types of institutions. These practices must become part of a common set of guidelines if they are to build a strong and diverse scientific workforce. Finally, diversity program development, which supports the success of URM trainees, is a matter of priority, not exclusivity. These same programs must be of value to and provide benefit to non-URM trainees as part of their broader impact and application.

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