Diversity in chemistry: catalyzing change

Irving R Epstein

African Americans, Hispanics and Native Americans are significantly underrepresented in chemistry and related sciences. An innovative approach based on course revision, peer support, precollege training and strong mentoring offers promise for engaging and retaining more underrepresented minority students and more members of the majority population in these fields.

It is not an exaggeration to say that the underrepresentation of African Americans, Hispanics and Native Americans in the scientific workforce is becoming a national crisis. In the past decade, reports by the American Association for the Advancement of Science[1], the US National Science Board[2] and the US National Science Foundation[3] have pointed out that our country's continued success in science is seriously threatened by the fact that white males make up over two-thirds of the scientific workforce but represent only about one-third of the population—a figure that is expected to shrink to one-fourth by 2050. Anyone who teaches an introductory science course at one of this country's elite universities is familiar with the sea of white faces he or she encounters, and the tendency of that ocean to whiten even more as the semester progresses and as one moves up the ladder of courses. Vast sums have been spent by government agencies, private foundations and educational institutions in an attempt to increase the numbers of underrepresented minority students (URMs) in science and medicine, but the list of success stories is dauntingly small.

Concerns for economic survival, social justice and scientific excellence all argue that we cannot afford to have a substantial segment of our population excluded from the scientific endeavor, particularly since the solutions to many of our most important problems—energy, environment, health and water, for example—require scientific expertise and creativity. Moreover, the brain drain that has brought us so many exceptional scientists from other nations may be on the brink of reversing direction. A diverse pool of scientists is essential not only to provide sufficient numbers of researchers but also to harness a broad range of outlooks and experience in tackling complex problems. In this Commentary, I consider some of the reasons for the dearth of URMs in science—particularly in chemistry—and some possible approaches for addressing this situation.

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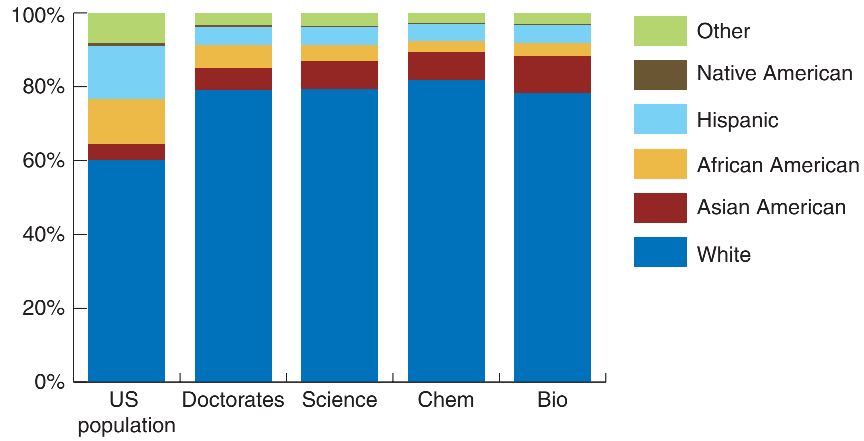

Figure 1 2005 data on the US population and doctorates awarded. Data are given for total doctorates awarded, total science doctorates awarded, chemistry doctorates awarded, and biological sciences doctorates awarded. Sources: US Census Bureau 2005 American Community Survey (www.census.gov/acs/www) and US National Science Foundation Division of Science Resources Statistics Survey of Earned Doctorates (www.nsf.gov/statistics/srvydoctorates).

The problem

The data in **Figure 1** clearly show that (i) the proportion of doctoral degrees awarded to URMs is far smaller than their share in the general population and (ii) this disparity is more marked in the sciences and still greater in chemistry and, to a slightly lesser extent, biology. A colleague at Harvard reports that most undergraduates who initially express an interest in studying science end up in another discipline, and that this "science dropout rate" is significantly higher among URMs and economically disadvantaged students. This situation is mirrored at my own institution. We need to ask ourselves why science is unattractive to so many students, particularly (but by no means exclusively) to URMs.

General chemistry is the first course in the biology, chemistry and premedical sequences at Brandeis and at many other universities. Most students taking the course view it as a necessary evil: something they must endure in order to get to what they really want to do—study biology or obtain admission to medical school. This attitude, which our current courses do little to change, is harmful to the morale of their more interested peers and leads to a high dropout rate from the science and premedical tracks. It also tends to produce "survivors" who lack intellectual curiosity and creativity, even if they do manage to become physicians or scientists. Fortunately, some students manage to retain their sense of wonder and excitement about science, but we need to significantly increase the size of this relatively small group.

The problem is endemic to science courses at many levels. After speaking with a group of high school science students, the late Carl Sagan concluded that "They memorize 'facts'. But, by and large, the joy of discovery, the life behind those facts, has gone out of them. They're worried about asking 'dumb' questions; they're willing to accept inadequate answers; they don't pose follow-up questions…"[4]. Sheila Tobias, one of the most thoughtful analysts of the difficulty of attracting students to science, hired a group of bright graduates from nonscience fields to sit in as participant-observers of introductory science courses. One *summa cum laude* literature graduate wrote of his physics experience, "There are no sad faces on this, the last day of class. No one will miss this chore. No one will say to himself or herself, 'I really enjoyed that', or 'that was an interesting learning experience'. Instead, people will congratulate themselves on having made it, will be happy with their 'B' or 'C', and will very soon forget anything pertaining to physics"[5].

This negativity that pervades introductory science courses, including general chemistry, has an especially pernicious effect on the retention of URMs, who often feel underprepared and isolated in the science classroom and laboratory. The pervasive lack of any notions about possible career paths to which the study of chemistry might lead is another deterrent to the persistence of URMs in chemistry. Few students can imagine a chemistry degree preparing them for anything except medical school or teaching chemistry, and URMs are even less likely than their classmates to have encountered a family member or acquaintance who has entered a different kind of career starting from scientific training.

Solutions: can chemistry be made more attractive?

The forces that push students away from science are not unique to URMs or to chemistry, though they probably exert more influence on minority students, especially those in chemistry, because of chemistry's place at the gateway to the university science curriculum. Two goals need to be pursued: chemistry must be made more attractive to students in general, and specific efforts must be made to recruit and retain more URMs in science.

Figure 2 Glowing pickle demonstration. The smoke and odor generated in the middle frame before the pickle begins to glow help to heighten the students' attention.

One approach to increasing chemistry's appeal is to try to recreate the sense of curiosity and wonder that first lures students into science but that so often vanishes as they proceed through the standard set of high school and college courses. If one asks science students what got them interested in studying science, one typically hears about an inspiring teacher and an early fascination with watching ants build their dwellings, or with observing substances change color, make loud noises or produce noxious odors on mixing. A key point, based on feedback from several hundred students I have taught, is that it is at least as important to motivate students to understand the material as it is to teach them the material, and that class time ought to be apportioned accordingly. Major concepts, such as thermodynamics and quantum theory, recur in different contexts and at varying levels of sophistication as one moves through the curriculum. Not even the best students grasp a complex concept completely the first time they encounter it. Each time they see it again, perhaps in physics or biology rather than in a chemistry course, they appreciate it in greater depth and breadth, grasping more of its details, implications and subtleties. If they don't get everything the first time (and no one ever does), it is more important to keep them coming back with minds that are open to further exploration of material they've already been exposed to than to increase their immediate level of understanding from, say, 55% to 62%. Current teaching methods, at least in my own department and in those of colleagues I have spoken with recently, seem to have lost sight of this goal.

When I ask my students to identify "those aspects of the course you found most useful or valuable for learning," they frequently cite "the demonstrations." Asked how to improve the course, many again respond, "Do more demonstrations." One of the most articulate students wrote, "Find ways to utilize multiple intelligences in the classroom. The lectures seemed to be equivalent to...the book. I can read the book myself. More demonstrations... and specific quantitative examples…would be helpful." Students seek not just passive enlightenment but active motivation. Another of Sheila Tobias's participant-observers opined after a semester of general chemistry, "Students, properly motivated, can learn this stuff with little difficulty…. Professors are going to have to rethink their strategies, along with their priorities, if students like me are going to be attracted early on, when it really counts, to science"[5].

With support from the Howard Hughes Medical Institute (HHMI), I have embarked on a project that is designed to (i) make introductory chemistry more appealing to students in general and (ii) help recruit and retain in science more URMs in particular. The general chemistry course is being reshaped to use more active learning techniques; for example, posing multiple-choice questions about the reading material to students, asking them to "vote" on the correct answer, and then having them discuss the problem with their neighbors before voting again. Demonstrations will play a major role. Students show far more interest in atomic spectra after seeing a pickle emit an orange glow when a current is passed through it[6] (**Fig. 2**) than if one simply presents them with diagrams of energy levels or even elegant slides of actual spectra showing the sodium orange line.

The lack of connection between lecture and laboratory is another persistent (and legitimate) student complaint about general chemistry. I plan to follow classroom demonstrations whenever possible with related, ideally open-ended, laboratory experiments; for example, analyzing the light emitted when an electric current is passed through a variety of "glowing veggies"[7] that have been marinated in solutions containing a series of metal ions.

I also intend to exploit the students' fascination and facility with video games. In collaboration with experts at the Massachusetts Institute of Technology, we are developing a set of games that enable students to learn by "playing with" key concepts in chemistry. For example, the gas laws and the kinetic-molecular theory invariably evoke yawns when taught in the conventional fashion. Enabling students to control the parameters and analyze the results of a video game in which particles bounce off each other and the walls of the container may actually make them want to understand temperature, pressure, volume and how they are related in ideal and even nonideal gases.

Finally, one needs to address the issue of what happens after studying chemistry. Students from disadvantaged backgrounds are often (quite legitimately) under heavy parental and internal pressure to study a subject that will lead to a financially and personally rewarding career. They are typically unaware of the fact that chemistry can open the way to working in such areas as the pharmaceutical industry, intellectual property law, venture capital, science journalism, environmental protection and public policy. Fellow HHMI professor Catherine Drennan is developing a library of video interviews with chemists in a variety of fields. In the interviews, the chemists describe what they do and how chemistry has prepared them to address important intellectual and societal issues. I plan to incorporate these videos, which also demonstrate that "the face of chemistry" includes women and URMs, into the curriculum of my introductory course.

Solutions: a science posse to the rescue?

In attempting to increase URM participation in the sciences, one might start by looking at what has worked in the past. Probably the most successful efforts have rested on the endeavors of a single dedicated individual, who is almost always a member of a minority group and who serves as both a role model and a catalyst. Examples of such programs include the undergraduate Meyerhoff Program at the University of Maryland, Baltimore County, led by President Freeman Hrabowski[8], and the graduate PhD program at Louisiana State University, which, under the direction of HHMI professor Isiah Warner (see http://jchemed.chem.wisc.edu/JCEWWW/Features/eChemists/Bios/warner.html), produces more African American PhDs in chemistry than any other program in the country.

Given the paucity of URMs on the science faculties of American universities, an attempt to duplicate such models on a wide scale does not yet appear to be feasible. A more widely applicable route can be found in Uri Treisman's efforts to improve minority student performance in calculus at the University of California, Berkeley[9]. Treisman sought to understand why most African American students taking first-term calculus were getting Ds and Fs. Through extensive survey research and careful collection and analysis of data, he demonstrated that several widely held assumptions (for example, poor motivation, inadequate preparation, lack of family support, and low income levels) cannot explain the situation. He then performed an experiment in which his team carefully followed the activities of 20 African American and 20 Chinese American calculus students. He concluded that the main difference was that "the black students typically worked alone," whereas "the Chinese students learned from each other." Using this insight, he constructed "an antiremedial program" that emphasized "group learning and a community life." The results were dramatic, with URM participants in the program outperforming not only their minority peers but also their white and Asian American classmates.

For the past nine years, Brandeis has hosted a program that shares many features with Treisman's program. The Posse Program is conducted in collaboration with the Posse Foundation (www.possefoundation.org), an organization that selects and trains "posses" of inner-city students, who are largely but not exclusively URMs. The students are chosen for their academic potential and leadership abilities, though their traditional credentials (for example, standardized test scores) generally fall below Brandeis's norms. Like Treisman's program, participation in Posse is an honor, not a remediation; it is not a "minority program," though most of the participants are URMs. Older students are role models and academic resources for younger ones, and participants are given realistic expectations about what it takes to succeed. Posse Scholars undergo an eight-month training program as high school seniors, during which they participate in workshops that not only strengthen academic skills but also address such topics as team building and group support, cross-cultural communication, time and financial management, and adapting to college life. Once they arrive on campus, each Posse of ten students is provided a mentor (typically a graduate student or staff member) with whom they meet weekly as a group and individually every two weeks. The training also gives Posse Scholars the self-confidence to take full advantage of the student support services (for example, tutoring) offered by the university.

Posse has been extremely successful. When Brandeis took its first Posse in 1998, we were the third institution to participate. Today there are Posses at 26 universities across the country, the graduation rate for Posse students is better than 90%, and in 2006 there

Figure 3 Brandeis Posse IX with mentor Kenroy Granville (back row, left).

were more than 7,000 applicants for 347 Posse Scholarships. In addition to succeeding in the classroom, Brandeis's Posse Scholars (**Fig. 3**) have also become leaders within the campus community. Although they provide invaluable mutual support for one another, Posse students do not isolate themselves, for example, by sitting together in a corner of the cafeteria; rather, they reach out to other minorities and to the majority community. For all its success, however, Posse does not produce scientists. In a typical Brandeis Posse of ten, three or four students may start out taking general chemistry, but, even in a good year, only one will complete a science major. Our experience is typical of other Posse schools.

With the help of HHMI and the Posse Foundation, we have begun to construct a program of Science Posses that builds on the successful aspects of the existing program but adds features tailored specifically to science. Some of the key elements include (i) creating a network of New York City high school science teachers to identify and recommend students suited for the program, (ii) developing a "Dynamic Assessment Process", a series of team and individual exercises and games to assist in selecting the most appropriate students, (iii) requiring a two-week on-campus 'boot camp' between the high school training program and matriculation aimed at providing both necessary skills and a realistic view of the rigors of university science, and (iv) guaranteeing each student a paid job in a research laboratory starting in his or her initial semester.

The last two items in particular merit further discussion. Conversations with URMs who have left science suggest that a mismatch between expectations and reality is a major factor pushing students out of science. Many of these students come from high schools with weak science programs. Though they have typically done well relative to their classmates, they have not been challenged (in terms of the intellectual level or the time commitment) the way they will be challenged in their first university science courses. The boot camp is meant to bridge that gap. Also, having a tight-knit group of students, most or all of whom are facing the same doubts about their ability to succeed in science, should provide far more support than the situation many URMs currently encounter, in which each one fears in isolation that he or she is the only student in the class who is struggling so hard. Providing students with lab jobs at such an early stage is an effort to take advantage of a fact that most URMs (and indeed most students and nonscience faculty) are unaware of: research groups in science constitute a source of community and support—exactly the sort of connection that so many first-year students seek when separated from their families for the first time. Given that most Posse students would otherwise hold less intellectually stimulating term-time jobs to earn needed financial resources, this innovation seems like an ideal way to provide additional intellectual and social impetus toward science. A similar job program under the direction of HHMI professor Richard Losick at Harvard University has resulted in the retention in science of 31 out of 34 students from disadvantaged backgrounds.

Conclusion

Although this Commentary is written from an American perspective and focuses on chemistry, conversations with colleagues from other countries and other disciplines suggest that many of the issues addressed here arise in their settings as well, though the identity of the underrepresented group or the subject matter may differ. If we can succeed in making chemistry more appealing to students by reawakening their instinctive curiosity about the world, and if we can use peer support and other mechanisms to attract and retain more URMs in chemistry, the impact will be felt well beyond a single discipline, a single university, and a single nation.

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COMPETING INTERESTS STATEMENT

The author declares no competing financial interests.

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