Chapter 15

Critical Mass Takes Courage: Diversity in the Chemical Sciences

Sibrina N. Collins*

The Marburger STEM Center, Lawrence Technological University, Southfield, Michigan 48075, United States
***E-mail: scollins@ltu.edu**

Diversity in science remains a critical issue facing the United States. Advocacy and support of diverse candidates is essential to the development of a diverse pool of chemical professionals. This article highlights the careers and intellectual achievements of successful women and scientists of color in both academia (R1 and undergraduate institutions) and industry. Broadening participation remains an ongoing challenge for our society and we need strong STEM advocates and STEM organizations to continue their efforts, which will lead to a diverse STEM workforce reflective of the U.S. changing demographics.

Introduction

In order to build a robust pipeline of diverse scientists, STEM advocates must be courageous, even when there isn't a diverse pipeline. A diverse pipeline should begin by building a critical mass of students enrolled in STEM departments at U.S. colleges and universities, which can only be accomplished with a strong recruitment *and* retention strategy. Furthermore, faculty, deans and staff must be committed to developing a strategic plan focused on supporting a diverse STEM community. When I was a chemistry graduate student at the Ohio State University (OSU) in the mid-1990s, I was one of eight African American students (critical mass) enrolled in the program with approximately 200 graduate students. The department chair at that time, Professor Matt Platz, invited us for lunch at the faculty club. We had a very candid conversation with Professor Platz about diversity in chemistry. He said to us, "Tell us what we need to do to keep you

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here." Professor Platz understood the importance of support for students of color in chemistry, which is absolutely critical for their success. Since that day back in 1994, I have been on a journey to understand why so few women and people of color pursue STEM (science, technology, engineering, mathematics) careers. My experiences as a graduate student in the Department of Chemistry at OSU were discussed in an editorial that I published in *Chemical & Engineering News* previously (*1*). Thus, my graduate school experiences essentially "planted the seed" for me to become a strong advocate for diversity in STEM.

Furthermore, a faculty diversity study (*2*) conducted by Professor Donna Nelson (University of Oklahoma) and Collins, "determined the representation, by race, rank and gender of tenured and tenure-track chemistry professors" at several HBCUs (Historically Black Colleges and Universities) compared to the faculty at the 'top 50' chemistry departments based on National Science Foundation (NSF) chemical expenditures. The results of this study indicated that over 50% of HBCU chemistry faculty were Black compared to only 1.2% at the "top 50" chemistry departments (*3*). Although this is a significant and troubling disparity, it is unknown how many Black chemists actually applied for faculty positions at the "top 50" chemistry departments, or were invited for on campus interviews. However, this study does underscore the importance of increasing diversity in STEM, namely in academia, industry, and government. In this paper, discussions will focus on the importance of STEM diversity, biographical profiles of underrepresented chemists and advocacy and support groups that are critical to broaden diversity in the chemical sciences.

STEM Diversity Matters to All of Us

Recent data reported by the National Science Foundation (NSF) clearly indicates the ongoing challenges for broadening participation in the STEM disciplines (*4*). White men and women hold over 70% of the STEM-related occupations compared to 5% of Black men and women, 6% of Hispanic men and women, and 17% of Asian men and women. These current statistics are not reflective of the changing demographics of the U.S. population. According to the U.S. Census Bureau, over 30% of the U.S. population are African American (13.3%), Hispanic (17%), and American Indian and Alaska Native (1.2%).

In 2015, a thought-provoking report authored by Maeghan Ouimet (*5*) entitled, "5 Numbers that Explain Why STEM Diversity Matters to All of Us" makes a very strong argument why broadening participation in STEM is critical to our future. "Evolving ourselves and our society for the better through technology will require a far more diverse talent pool in science and engineering fields than the alarmingly resilient White- and Asian-male pool we're running with today," writes Ouimet. In fact, the estimated size of the STEM workforce by 2018 is 8,650,000. "Technology companies alone—led by giants like Facebook, Amazon, and Apple –will need to fill more than 650,000 new jobs by 2018. Two-thirds of these new hires will be STEM talent." This underscores the importance and urgent need for STEM talent to fill these positions.

Biographical Profiles of Chemists

In order to achieve a critical mass of the next generation of chemists, it is imperative that we need the voices and influence of strong advocates, supporters and pioneers in the chemical sciences to "sound the alarm" of this important work. There are many pioneers in the chemical sciences who represent diverse voices. We begin with the story of Dr. Saint Elmo Brady, the first African American to earn a PhD in chemistry.

Saint Elmo Brady: Chemistry Trailblazer

The year 2016, marks 100 years of African Americans earning doctoral degrees in chemistry. The eldest child of Thomas and Celesta Brady, Saint Elmo Brady was born in Louisville, Kentucky in December of 1884. He earned his undergraduate degree in chemistry from Fisk University (Nashville, TN), an HBCU in 1908. After graduation from Fisk, Brady took a teaching position at Tuskegee Normal and Industrial Institute (now known as Tuskegee University) in Alabama and worked with Dr. Booker T. Washington and George Washington Carver (*6*).

Brady continued his studies and enrolled in the graduate chemistry program in 1912 at the University of Illinois, earning his M.S. degree in chemistry in 1914. Brady completed is doctoral degree in 1916 under the direction of Professor Clarence Derick, with the thesis entitled "Divalent Oxygen Atom."

Brady and Derick co-authored three abstracts which appeared in *Science* Magazine (1915-1916). Brady also co-authored a paper with G.D. Deal (*7*), which appeared in the American Chemical Society's *Journal of Industrial Engineering Chemistry* in 1916. Furthermore, Brady was the sole author of a paper (*8*) published in the *Journal of the American Chemical Society* (JACS) in 1939, while teaching at Fisk University. Although Brady did not publish many peer-reviewed articles, his impact regarding chemistry education is undeniable. He spent the majority of his career teaching at HBCUs, and taught many students at Fisk University, Howard University (Washington, DC) and Tougaloo College (Tougaloo, MS). Furthermore, he also established a summer program (in collaboration with the University of Illinois) focused on infrared spectroscopy for faculty.

Gregory Robinson: Inorganic Chemistry Pioneer

Inorganic chemistry is a diverse discipline that includes the fields of bioinorganic chemistry and organometallics (*9*). There have been numerous important scientific contributions (*10–13*) to the field of inorganic chemistry including the preparation of nickel tetracarbonyl, $Ni(CO)_4$ by Mond in 1890; the discovery of ferrocene, $(C_5H_5)_2Fe$ by Kealy and Pauson in 1951; the development of the anticancer drug cisplatin, cis-$Pt(NH_3)_2Cl_2$; the discovery of the "DNA Light-Switch" complex $[Ru(bpy)_2(dppz)]^{2+}$ (bpy = 2′2-bipyridine, dppz = dipyrido[3,2-a-2′,3′-c]phenazine), and the discovery of the first quadruple metal-metal bond in dipotassium octachlorodirhenate(III) dihydrate,

$K_2[Re_2Cl_8]{\cdot}2H_2O$ (Figure 1) by the late eminent inorganic chemist F. Albert Cotton (*14*, *15*) in 1965. (Quadruple bonds between two metal centers consist of a sigma bond, two pi bonds, and one delta bond. The delta bond is formed by overlap of the d_{xy} orbitals of the Re metal centers.) Regarding quadruple metal-metal bonds, Cotton once stated, "Today the concept of quadruple bonds has become common place, with hundreds of compounds containing them and the physical and theoretical characterization of them is very comprehensive" (*15*). Thus, inorganic chemistry is a broad field with a rich history.

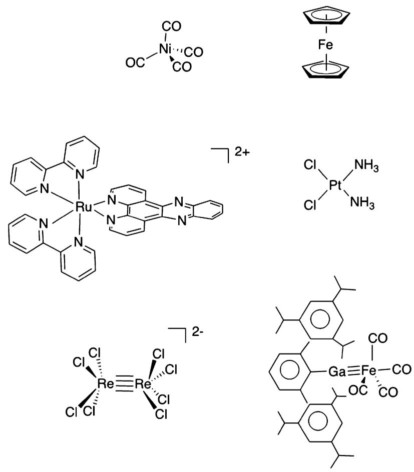

Figure 1. Structures of selected inorganic and organometallic compounds.

Professor Gregory H. Robinson, a pioneer in the field inorganic chemistry, earned his Ph.D. from the University of Alabama in 1984, under the direction of Professor Jerry L. Atwood. Robinson, the *Franklin Professor and Distinguished Research Professor of Chemistry* at the University of Georgia (Athens, GA), has published hundreds of peer-reviewed papers and book chapters focused on multiple bonding involving main group elements and the structures of organometallic–inorganic compounds.

In 1997, Robinson published two articles in the journals *Organometallics* and the *Journal of the American Chemical Society*, focused on the first reported ferrogallyne, which contained an iron-gallium (Fe-Ga) triple bond (Figure 1), and the first gallyne compound, which contained a triple bond between the two gallium metal centers (*16*, *17*). At the time, Robinson's research efforts were highly controversial because there were no prior published reports in the literature with compounds containing iron-gallium or gallium-gallium triple bonds. One of Robinson's fiercest critics was the late Professor F. Albert Cotton at Texas A&M University. Cotton, who earned his Ph.D. from Harvard University in 1955, under the direction of Sir Geoffrey Wilkinson, was well-known and highly respected for his research efforts focused on metal-metal bonded complexes. The Robinson-Cotton debate was widely publicized in *Chemical and Engineering*

News (*18*, *19*) and is a certainly historic moment in the field of inorganic chemistry. In fact, Robinson's postdoctoral researcher at the time, Dr. Jianrui (Hank) Su, who prepared the ferrogallyne compound earned his Ph.D. under the direction of Cotton in 1996.

Robinson and his research team reported that the linear Fe—Ga bond was the shortest bond length reported (2.2248(7) Å) compared to related complexes reported in the literature. Regarding the nature of the Fe—Ga bond, Robinson reported, "It is our position that, in addition to the formal iron—gallium double bond, the linearity about the gallium center enables additional overlap from a filled d orbital (of appropriate symmetry) with the remaining empty p orbital on gallium, thereby forging a second π-bond" (*17*).

Cotton reportedly told C&EN at the time (*19*), "That's no more a triple bond than I'm a Dalai Lama!" Cotton and his research team used density functional theory (DFT) calculations on model systems to refute Robinson's claims. Based on theoretical predictions, Cotton concluded that the ferrogallyne contained a single Fe—Ga bond, not a triple bond (*20*). Cotton argues that a single bond between Fe—Ga would lead to a stable 18-electron configuration. "Any further increase in this bond order can occur in only one way, namely, by back-donation of electrons on the iron atom to empty orbitals on the gallium atom. To obtain a Ga—Fe bond order of 3, there would have to be two fully formed Fe→Ga dative π bonds." Furthermore, Cotton and Feng also concluded that if the compound contained a triple Fe—Ga bond, the π-back bonding between the iron atom and the four electron-withdrawing CO ligands, wouldn't be significant and the CO stretching frequencies should be "unusually high."

In 1998, Cotton, Cowley, and Feng published a second paper focused on DFT calculations of model complexes containing Ga—Ga metal bonds (*21*). Their theoretical predictions suggested that the Ga—Ga bond was a double bond, not a triple bond. "For a recently reported compound alleged to contain a Ga—Ga (triple) bond the calculations point to a different formulation in which there is only a double bond and a significant role for noncovalent interactions," wrote Cotton, Crowley, and Feng.

Robinson et al. (*22*) published a strong rebuttal and reported their own DFT calculations and concluded that the gallyne compound contained a Ga—Ga metal bond "to be between triple and double in character despite the relatively long bond length." Robinson strongly argued that "the nature of a chemical bond is determined primarily by electronic structure, not the molecular geometry. A weak triple bond is different from a double bond, which in turn is different from a single bond, even though the bond lengths may be similar."

Robinson is a pioneer in chemistry and his ground-breaking research was an exciting time for the field of chemistry. His research has enhanced the narrative of understanding the chemical bonding interactions of inorganic and organometallic compounds. Since the public debate, Robinson has continued his research efforts focused on multiple bonding in heavier atoms. In 2008, Robinson and his research team reported the first compounds that contained a hafnium—gallium and hafnium—indium metal bonds (*23*). Furthermore, Robinson was most recently awarded the 2013 ACS F. Albert Cotton Award in Synthetic Inorganic Chemistry (*24*).

Julia Chan: Solid State Chemistry Trailblazer

Professor Julia Chan is a prolific researcher and trailblazer in the field of solid-state inorganic chemistry and a strong advocate for diversity in STEM. Chan earned her undergraduate degree in chemistry from Baylor University (Waco, Texas) in 1993, where she conducted laser photoacoustic spectroscopy research. Chan then pursued her doctoral degree from the University of California-Davis in 1998, under the direction of Professor Susan Kauzlarich, where she investigated the properties of zintl phases and carbides (*25*). Chan was a National Research Council Postdoctoral Associate in the Materials Science & Engineering Laboratory at the National Institutes of Standards and Technology (NIST), investigating oxide materials for wireless communications.

She joined the faculty in the Department of Chemistry at Louisiana State University (Baton Rouge, Louisiana) in fall 2000 as an Assistant Professor. Louisiana State University is the leading producer of underrepresented minorities earning doctoral degrees in the chemical sciences (*26*, *27*). Chan was awarded tenure and promoted to Associate Professor at LSU in 2005, and later promoted to full Professor in 2009. In summer 2013, Chan joined the Department of Chemistry at the University of Texas at Dallas (UT Dallas), an innovative institution established in 1969 that is on path to achieve Tier 1 status.

Professor Chan has a very strong and rigorous publication record (~150 papers) in high-impact journals with significant funding to support research efforts focused on solid-state chemistry, synthesis, and characterization of energy materials and crystal growth of extended solids. Chan et al. (*28*) recently published an article in the high-impact ACS journal, *Accounts of Chemical Research,* which provides an excellent overview of her research efforts in the laboratory. The motivation for crystal growth in the Chan laboratory focuses on the discovery of new compounds with "tunable" physical properties, which can lead to the development of new technologies that benefit society. Chan's research has focused on the synthesis of lanthanide-based ternary intermetallics (Ln:M:X) and complex stannides.

Chan is certainly a "change agent" regarding efforts focused on diversity in STEM. She has successfully mentored a diverse group of students over her career, specifically 17 PhD students and over 35 undergraduates while teaching at LSU. Seven of her PhD students have been women; eight of the PhD students are underrepresented minorities (1 Asian American, 7 African Americans), and one MS student (African American male). Chan currently has six graduate students (1 Hispanic woman, 1 Hispanic/American Indian male, 1 African American male) in her laboratory at UT Dallas, which also includes 4 undergraduate students.

Chan understands the importance of effective recruiting and supporting a critical mass of underrepresented students and has strong support from the UTD administration and colleagues. Regarding efforts to broaden participation at UT Dallas, she stated, "When I came to UTD in the summer of 2013, there were NO African American students (also very few domestic students). Now, we have two. This seems small, but we are making progress in just two years of me serving on the faculty at UTD. We only had 1 Hispanic student, and now we have six. It's one thing to have diverse students, but it is equally important to provide support."

Melissa Schultz: Analytical Chemistry Trailblazer

A native of St. Paul, Minnesota, Professor Melissa Schultz was a "change agent" who was truly passionate about young girls pursuing careers in STEM and the environment. Schultz earned her undergraduate degree in chemistry from Creighton University (Omaha, NE) in 1999. She continued her studies at Oregon State University earning a PhD in analytical chemistry in 2004, under the direction of Dr. Douglas Barofsky and Dr. Jennifer Field. She was awarded a National Research Council (NRC) Fellowship and was a postdoctoral researcher (2004-06) with the U.S. Geological Survey (USGS) National Water Quality Laboratory in Denver, Colorado.

In 2006, Professor Schultz joined the faculty in the Department of Chemistry at The College of Wooster, a small liberal arts institution located in Northeast Ohio (Wooster, Ohio). The College of Wooster is nationally known for the Senior Independent Study (I.S.) program, which is a senior capstone project, where students work under the direction of a faculty member focused on cutting-edge research. Schultz was a prolific researcher and nationally respected expert on mass spectroscopy techniques.

Schultz investigated the effects of antidepressants in aquatic ecosystems. She published several papers with Wooster students in high-impact journals including *Analytical Chemistry*, *Aquatic Toxicology*, and the *Journal of Chromatography A* (*29–31*). The target antidepressants in one study (*29*) focused on selective serotonin and norepinephrine reuptake inhibitors (SSNRIs) such as fluoxetine and sertraline. Schultz's writes, "Antidepressant pharmaceuticals are one of the most heavily prescribed in the United States; currently more than 10% of the U.S. population uses antidepressants. Since antidepressants are widely prescribed in the U.S. and are incompletely removed during municipal wastewater treatment, it is not surprising that these chemicals are being detected in our waterways." Furthermore, this study is significant because it is the "first to report the consistent detection of a suite of antidepressants in biosolids destined for land application over a multimonth study."

Tragically, on February 7, 2015, Professor Melissa M. Schultz died from injuries due to an automobile accident near her home in Wooster, Ohio. Over the course of her career at The College of Wooster, Professor Schultz supervised 30 Senior I.S. students majoring in chemistry and biochemistry and molecular biology. She also served as a champion of women pursuing careers in the chemical science and was a strong advocate for the environment. She leaves us with a proud legacy in the field of analytical chemistry.

Malika Jeffries-EL: Trailblazer in Organic Electronics

A native of Brooklyn, NY, Professor Malika Jeffries-EL is a prolific researcher in the field of polymer chemistry and a strong advocate for diversity in the STEM fields. Jeffries-EL began her college career at Wellesley College, earning undergraduate degrees in both chemistry and Africana Studies in 1996. She then enrolled in the graduate program at George Washington University earning an MS degree in 1999, and a PhD in 2002.

Jeffries-EL was a Mendenhall Fellow (one-year) at Smith College, before accepting a postdoctoral appointment in the research laboratory of Professor Richard D. McCullough at Carnegie Mellon University. In 2005, she joined the faculty in the Department of Chemistry at Iowa State University (Ames, IA). In 2012, she was promoted to associate professor with tenure. In January 2016, she joined the Department of Chemistry at Boston University.

Professor Jeffries-EL's research efforts focus on the development of organic semi-conductor materials and she has over 30 publications (with over 2,000 citations) in high impact journals such as *Macromolecules*, *Journal of Organic Chemistry*, and the *Journal of the American Chemical Society* (*32–34*). Most recently, she co-authored an article that was selected for the *Journal of Materials Chemistry C Hot Papers* (*35*), which focused on "benzobisoxazole cruiforms as emitters for developing high-performance deep blue OLEDs."

Furthermore, Professor Jeffries-EL has received numerous awards over the years for her achievements including the National Science Foundation (NSF) Career Award (2009), the Lloyd Ferguson Award from the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers (2009), and the ISU-College of Liberal Arts and Sciences Diversity Award (2011).

Professor Jeffries-EL is a staunch advocate for diversity in the chemical sciences. Most recently, a report released by OXIDE (Open Chemistry Collaborative in Diversity Equity) and *Chemical Engineering News* (*36*) indicated that only 4% of chemistry faculty at the "top 50" departments are underrepresented minorities. Jeffries-El stated, "That 4% figure is discouraging, but it is not surprising. We can't keep doing the same things and expect the statistics to improve. You have to be very intentional in your recruitment [efforts]."

Sharon Haynie: Pioneer in Corporate America

Dr. Sharon Haynie has some powerful advice for young people with aspirations to pursue a career in the chemical sciences (*37*). "Discern what moves you, distill these options and pursue what you love. More importantly, define it on the basis of creating a good life rather than a good living for yourself." Dr. Haynie is a pioneer in corporate America and has served on many ACS committees during her career.

A native of Baltimore, Maryland, Haynie earned her undergraduate degree in biochemistry from the University of Pennsylvania in 1976. She continued her education and enrolled in the chemistry graduate program at the Massachusetts Institute of Technology (MIT), and earned her PhD in chemistry under the direction of Professor George Whitesides in 1981. Haynie and Whitesides co-authored several research papers in high-impact journals such as *Applied Biochemistry and Biotechnology*, *Journal of Organic Chemistry*, and *Journal of the American Chemical Society* (*38*, *39*).

After graduating from MIT, Haynie joined the technical staff at AT&T Bell Labs and remained there four years. In 1985, she joined the technical staff at DuPont Company, where she has achieved great success during her career. Dr. Haynie was a member of the DuPont/Genencor research team that received the EPA Presidential Award for Green Chemistry, specifically for new innovation in developing a commercial bio-process to 1,3-propanediol. In 2008, she was the first woman to receive the NOBCChE (National Organization for the Professional Advancement of Black Chemists and Chemical Engineers) Percy L. Julian Award, which recognizes the remarkable achievements and legacy of Dr. Julian. The Percy Julian Award is the most prestigious award from the NOBCChE Organization to recognize the contributions of chemists and chemical engineers (*40*).

Although the statistics of African Americans working in the chemical industry are low, Dr. Haynie is one of the many shining examples of success in corporate America. Dr. Haynie has received several patents during her career at DuPont Company focused on methods for cultivating plants and artificial seeds, the manufacturing of *p*-hydroxycinnamic acid (pHCA), and development of methods to treat an oral cavity surface with a peracid-based benefit agent (*41–43*). Haynie is a champion for diversity in STEM and is a "change agent" for women and scientists of color working in the chemical industry.

Advocacy and Support

There are numerous programs and organizations focused on broadening diversity in the STEM disciplines. The goal here is not to provide an exhaustive list, but to highlight major programs from the National Institutes of Health (NIH), National Science Foundation (NSF), and recognize the efforts of the ACS, NOBCChE, SACNAS (Society for the Advancement of Chicanos and Native Americans in Science), AISES (American Indian Science and Engineering Society), NSBE (National Society of Black Engineers) and AAAS (American Association for the Advancement of Science).

NIH and NSF STEM Programming

The NIH MARC (Maximizing Access to Research Careers) is a research training program for undergraduate students from diverse backgrounds, specifically in the biomedical sciences. A key goal of this program is to prepare students for high-caliber graduate training at the PhD level. Established in 1982, the MARC program (formerly known as Minority Access to Research Careers) supports approximately 700 students annually (*41*, *42*).

In February 2016, NSF announced a new funding opportunity, namely NSF INCLUDES (Inclusion Across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science) Program. The goal is to "transform STEM over the next 10 years so that it is fully and widely inclusive." The first stage of NSF INCLUDES will fund up to 40 projects ($300,000 each) for two-year pilots. Subsequently, the successful pilot programs will be able to compete for "Alliance" awards of $2.5 million (*43*). The NSF LSAMP (Louis Stokes for Alliance for Minority Participation) was established many years ago to assist institutions in their efforts to increase the number of STEM graduates from diverse backgrounds (*44*).

The Impact of STEM Organizations and Societies

There is no question that STEM organizations and societies such as ACS, NOBCChE, NSBE, SACNAS, AISES, and AAAS have many programs and initiatives focused on broadening participation in STEM. These STEM organizations not only provide funding support such as travel grants, scholarships and fellowships for students, but offers networking and social support for women and scientists of color. Furthermore, these organizations also provide opportunities for professional development, which is needed for successful careers in STEM. Technical skills and soft skills are very important for STEM professionals, but effective mentoring experiences are also critical for a successful STEM journey. In addition, students have the opportunity to present their research results during the technical sessions held during scientific conferences such as LSAMP, SACNAS, NSBE, and ASIES. Students need opportunities to effectively communicate their scientific results, which is an important skill for future employment opportunities.

Finally, other programs such as the ACS Scholars Program and the McNair Scholars Program are long standing initiatives committed to broadening participation in the STEM fields (*45*, *46*). Established in 1994, the ACS Scholars Program has provided scholarship support to over 2600 students (51% African American, 43% Hispanic and Latinos, 6% American Indian) who are interested in the fields of chemical technology, chemistry, and environmental science. The McNair Scholars Program, named in honor of the late physicist and astronaut, Dr. Ronald McNair, offers McNair Scholars summer support to conduct cutting-edge research and travel funds to attend and present research during the McNair Conference.

Concluding Remarks

It is important to recognize the intellectual contributions of everyone in the STEM fields. Broadening participation remains an ongoing challenge for our society and we need strong STEM advocates and STEM organizations to continue their efforts, which will lead to a diverse STEM workforce reflective of the U.S. changing demographics.

Effective mentoring is a critical component to broadening participation in STEM. It is absolutely essential that STEM students understand that their mentor will provide critical support and truly believes the student has the potential to succeed in the STEM disciplines. Furthermore, the mentor must help the student develop solid critical thinking and communication skills in order to achieve great success as a STEM professional. Students need to expand their network and seek mentors that are not affiliated with their department or institutions for advice and guidance on career paths and professional development opportunities. A university research advisor can certainly provide technical training for a STEM student, but may not have a broad enough network outside of academia, which could be useful for mentoring STEM students with career goals in other chemistry-related fields (e.g. science and history museums, science journalism, patent law).

There is no “one size fits all” model for success in STEM. Diversity in STEM should matter to all of us because—quite frankly—we have STEM challenges that are important for the environment, national security and health. We absolutely need diverse perspectives to find solutions for these challenges. We need courageous people to lead the way and build the critical mass of STEM talent to ensure the future of the U.S. economy.

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