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Mentoring to Enhance Diversity in STEM and STEM-Intensive Health Professions

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Abstract

Effective mentoring is essential for promoting student success in the science, technology, engineering, and mathematics (STEM) fields. Engaging students in mentored learning communities and encouraging them to participate in research can promote retention in STEM. This is especially true for students from backgrounds that are underrepresented in these fields, including students from educationally- or socioeconomically-disadvantaged backgrounds.

Purpose: This manuscript is a scholarly perspective on the crucially important topic of mentoring in STEM and the STEM-intensive health professions (STEM+). Our purpose is to share our understanding of this subject as a means to mitigate the persistent underrepresentation in these fields and to offer our recommendations.

Materials & Methods: This manuscript draws on the literature and our experiences to develop recommendations for improving outcomes for diverse populations of undergraduate students who are pursuing majors in the STEM fields and aspire to careers in the biomedical sciences and/or STEM-intensive health professions.

Results: Undergraduate learning communities and mentored research activities promote continued engagement in STEM and also provide a competitive foundation for careers in these fields.

Conclusions: (1) Mentoring must be brought to scale through clearly articulated institutional and disciplinary prioritization of learning communities, with attendant assessment to monitor the impact of creating an environment that supports diverse students from underrepresented

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backgrounds. (2) Individual faculty members and principal investigators affiliated with academic institutions and stand-alone research facilities can enhance their mentoring role by welcoming underrepresented undergraduates into their laboratories. (3) Faculty members, administrators, and staff members must commit themselves to the success of each student who enrolls in a STEM+ program, rather than accepting high rates of failure as inevitable. (4) Increased interactions between first-year students and faculty members through experiences in mentored learning communities that promote authentic engagement and discovery are key to promoting the retention of diverse populations of students who are underrepresented in the STEM+ fields. (5) Learning communities can amplify the impact of an individual mentor. (6) Barriers to student success, such as weak preparation from high school courses, must be proactively and effectively addressed.

Keywords

STEM; mentoring; student success; undergraduate research; learning communities

Introduction

In the United States, science, technology, engineering, and mathematics (STEM) fields can form an undergraduate major and lead to a subsequent career (BLS, 2017; Pew 2021). Undergraduate studies in the STEM fields also serve as a foundation for admission to STEM-intensive health professions including medicine, dentistry, and veterinary medicine among others (NAAHP, 2021). For brevity, we aggregate these fields under the STEM+ moniker. Many of the STEM+ fields and occupations lack diversity, as analyzed in several recent reports (National Science Foundation, 2019; Freeman JB 2020; Okahana, Zhou, and Gao, 2020) that have spurred calls for action in order to create a more diverse workforce of the future (Handelsman and Smith, 2016; Hrabowski and Henderson, 2019, Freeman S, 2020, Tilghman et al., 2021). In these contexts, the lack of diversity is defined by underrepresentation of particular groups of people. These groups include women, individuals who identify as disabled, LGBTQIA+ (an inclusive term covering people of all genders and sexualities, such as lesbian, gay, bisexual, transgender, questioning, queer, intersex, asexual, allies and pansexual), and/or people who belong to one or more racial/ethnic minority groups. Underrepresented groups in STEM+ also include people who come from socioeconomically or educationally disadvantaged backgrounds and those who are the first in their families to attend a post-secondary institution. Students who are educated in low-resourced, underperforming K-12 environments may face enduring disadvantages that significantly encumber their opportunities to gain the transformative advantages of a STEM+ career. Without significant educational interventions, these societal inequities can be perpetuated in a repetitive cycle (Nieto and Bode, 2012).

The consequences of the lack of diversity in the STEM+ fields are wide-ranging, insidious, and deleterious. The personal and professional development of STEM+ practitioners is stunted by insufficient exposure to a variety of the lived experiences that reflect the wide array of cultures, races, languages, religions, gender identities in the U.S. today (Hu and Kuh, 2003). The lack of diversity also limits the richness of the professional environment for STEM+ practitioners who are unable to benefit from interactions with colleagues who bring different perspectives and nuanced understanding to bear on problems. As a result, candidate solutions may be too few and too narrow, thereby resulting in inappropriate prioritization and suboptimal solutions (Page, 2007). As a result of this lack of diversity, scientific productivity, as measured by publication data, is negatively impacted (Freeman and Huang, 2015). Moreover, recent work by Hofstra et al. (2020) demonstrates that U.S. Ph.D. students from underrepresented backgrounds innovate at higher rates than do students from majority backgrounds, yet their innovations are less impactful because their new ideas are discounted and less frequently adopted by other practitioners. Diverse STEM+ communities are positioned for greater success because they are more innovative and scientifically productive.

The lack of diversity in STEM+ likely emanates from and reflects systemic racism issues that pervade society. Most directly, disparities in access to high quality science and math education, starting in early childhood, have led to deep and persistent inequities that may be most evident in the fields of STEM+, given the strongly hierarchical organization of knowledge and practice in these fields (Elliott, 1996). A strong foundation in pre-collegiate education provides a significant advantage because it promotes admission to post-secondary institutions (Rodriguez, 2017), facilitates strong performance in undergraduate studies and STEM degree attainment (Maltese, 2008; Chen, 2009; Shaw & Barbuti, 2010; Hinojosa, 2016), and ultimately propels students to enter and complete graduate and professional programs in STEM+ disciplines (Hilton & Lee, 1988).

There have been many studies that document the underrepresentation of specific groups in STEM+ due to a myriad of challenges that must be overcome prior to entry into the workforce as STEM+ professionals (NASEM, 2016). In recognition of these difficulties faced by students from underrepresented groups, a number of strategies have been implemented to increase the number of these individuals in STEM+ including outreach programs (Kitchen Sonnert, 2018; U.S. Department of Education, 2010), academic support and tutoring programs (Toven-Lindsey, 2015), bridge programs (Kitchen Sadler, 2018; Ashley, 2017), and incentivized financial aid (Piper, 2015). At the pre-college and undergraduate levels, there also have been changes in pedagogical approaches that involve less reliance on large lectures and more emphasis on active learning (Freeman, 2014) through hands-on investigations and open-ended inquiry as means to engage students from all backgrounds in the processes of science. While many of these efforts have been studied in isolation from other institutional initiatives, others have been integrated into a full suite of offerings to support students' engagement and pursuit of post-secondary study of the STEM fields as an undergraduate major and/or as a foundation for admission to STEM+ graduate or health professional programs.

Two approaches to broaden participation in STEM+ that have garnered attention are the use of mentoring (NASEM, 2019) and learning communities (Johnson, 2014) to support students from diverse and underrepresented backgrounds as they enter and progress through their undergraduate studies (Dagley-Falls, 2009). The integration of these strategies to create mentored undergraduate learning communities composed of diverse students and faculty can promote students' affiliation with the STEM+ fields and their post-secondary institutions (Gabelnick, MacGregor, Matthews, & Smith, 1990). The connections forged through mentored learning communities are most impactful when they occur within the first semester of college (Laufgraben, 2005); they increase the likelihood that students will persist in these fields, graduate, and become STEM+ practitioners. Through mentored undergraduate learning communities, students can study advanced topics in their major, explore the broader social context of the STEM+ fields, learn about the wide array of STEM+ careers through research and job shadowing, and develop a network of trusted peers and mentors who can support their intellectual growth and development.

Mentored Undergraduate Learning Communities as inclusive and supportive environments

New undergraduate STEM+ students must immediately establish foundations that will support their academic and personal success due to the rigorous and hierarchical nature of the STEM+ program of study (Dagley-Falls, 2009). Students who identify as members of groups that are underrepresented in the STEM+ fields are often at high risk at this point in their pathway to a STEM+ career since they have entered an often unfamiliar and even intimidating environment. In response to assessments of the needs of these students and their reports of the challenges they have encountered, mentored undergraduate learning communities have emerged as a successful means to support the needs of diverse groups of students.

Mentored undergraduate learning communities for first-year STEM+ students can be effectively based on a co-enrollment cohort model that leverages the standardized organization of these programs of study. STEM+ students typically take introductory courses in mathematics, English, and sciences, along with additional courses in humanities, social sciences, and foreign languages (Johnson, 2014). Grouping new first-year students into co-enrollment cohorts can be based on their intended major, placements in math and English, academic goals within their major discipline, and identified professional goals. This cohort model creates a community of students who are in the same sections of the core classes and fosters the development of mutually-supportive friendships.

The mentored undergraduate learning community can be augmented by the addition of a major-specific, first-year seminar course that explicitly brings the cohort together with a dedicated mentor (Lifton, Cohen, and Schlesinger, 2008). This seminar course provides opportunities to learn about resources for academic, professional, and personal development, as well as gain support and encouragement to pursue such opportunities. Moreover, the seminar course provides a time and place for building a cohesive community that imbues each member with an identity as a valued contributor and builds accountability to other members of the group. Perhaps the most important role of the seminar for first-year students is that it can pique their curiosity about research on advanced scientific topics more than any other component of the introductory STEM coursework. The seminar can focus on contemporary scientific issues that entail more specialized understanding than is typically developed in the first year courses. Seminars focused on reading and discussion of cutting-edge research can help to establish foundational skills in formulating research questions and testable hypotheses, specifying research goals and objectives, identifying potential challenges and means to overcome them, and developing advanced skills in writing and the use of digital multimedia. Students are motivated to apply what they have learned in their coursework and are eager to complement their new-found knowledge with more focused advanced learning that goes beyond the material covered in introductory gatekeeper courses. Small group collaborations in a workshop-like seminar class setting, with facilitation by more advanced near-peer mentors or faculty mentors, can allow students to raise questions and share ideas more readily than is possible in the large lecture classes that first year students typically take.

While mentored undergraduate learning communities are valuable for all students, they may be most important in promoting the success of students from groups that are underrepresented in STEM+. The successful transition from high school to the undergraduate setting is facilitated when students immediately become part of a diverse, inclusive, supportive, and non-competitive learning community. Mentored undergraduate learning communities help students know that they belong, are known and valued as individuals, and are connected to a diverse group of individuals within the college community including peers, peer mentors, faculty and staff mentors, and academic advisors. Through these communities, active connections among the students and mentors through email, text messages, or even informal campus encounters can offer support, guidance, and encouragement, even for those who are too shy to engage on their own. Once students recognize that every member of the community receives support and mentorship, they frequently extend the culture on a peer-to-peer basis, as well as gain the support of more advanced peer mentors and alumni who are further along on their professional pathways. A diverse student population may enhance the formation of supportive communities, since this may be students' first opportunity to meet and know peer students from a wide variety of backgrounds who share similar interests, passions, and challenges. (Pike, 2010) The trusting friendships that form within the cohort seem to deepen the commitment to mutual support and provide a foundation for enduring relationships that persist throughout the undergraduate years and beyond.

The mentored undergraduate learning environment can also play an important role in preserving a mutually-supportive environment rather than allowing a competitive dynamic to take hold. This type of mentored learning community experience may be especially supportive for premedical and other STEM+ students who intend to pursue training in the STEM-intensive health professions, since they typically feel pressure to achieve the highest possible standard of academic performance and to engage in highly selective academic enrichment opportunities. Since these prime enrichment opportunities are often offered to only small numbers of students, there can be intense competition for these coveted slots in what is widely viewed as a zero-sum game with their peers. The mentored undergraduate learning community can tamp down the interpersonal competition by expanding awareness about a broader array of opportunities and supporting all students in the pursuit of such activities. Near-peer mentors, for example, can help to guide the first-year students by sharing information about their work in research or clinical laboratories, job shadowing opportunities, enrichment programs, research-oriented community programs, and relevant clubs and on-campus speakers, events, and seminars.

The mentored undergraduate learning community can also help students to successfully run the gauntlet of the introductory STEM+ coursework. There have been numerous notable initiatives to enhance STEM instruction, particularly for introductory students. Still, at many, if not most, undergraduate institutions, large introductory STEM courses that use didactic educational strategies and require extensive memorization are the norm. Introductory science laboratory classes, while intended to address the need for engaged scientific learning, are often formulaic recapitulations that lead to known outcomes (Seymour, 2004) and do not provide students with a feeling that they have been welcomed into a larger community of scientists. Pedagogical choices in introductory gatekeeper courses are often made for faculty expedience, and often preclude STEM+ students' exposure to integral aspects of these fields that are most appealing to practitioners, such as hypothesis generation and testing, active discovery, and the collaborative culture of research laboratory environments. Large lecture-based introductory STEM classes may inadvertently discourage students who struggle in the anonymity of this learning environment because they feel alone and may, in silence, question their own abilities to succeed. This may be especially true for students from underrepresented backgrounds who may not feel empowered to speak up, share their anxieties and insecurities, and seek help and support.

Mentored undergraduate learning communities can help first-year STEM+ students to feel a sense of belonging through their use of a laddered mentoring approach that is prevalent in research laboratories. In most research groups, the principal investigator mentors a number of post-doctoral scholars, graduate students, undergraduate students, and even high school students through a combination of individual and group meetings. All individuals serve as mentors to those who are less experienced than they are, in a near-peer mentoring model. In addition, lab members at the same level of experience also mentor one another and learn together. In a mentored undergraduate learning community, the faculty mentor takes on a role that resembles that of the principal investigator, alumni and more advanced students take on roles that resemble those of post-doctoral scholars and graduate students, and the first-year undergraduates mentor one another and learn together as peers. In this model, the mentoring impact of a single faculty member can be amplified to reach a significant number of students by giving them a network of people who can support them as they affiliate with the institution and develop their identity and disciplinary expertise. The more experienced members of the learning community feel pride and accomplishment in seeing their mentees progress and succeed in their studies. Moreover, these relationships can form the foundation for a long-standing professional network of colleagues.

The Role of Mentored Undergraduate Research and Research Universities

Participation in undergraduate research provides a crucial developmental opportunity for undergraduate students in STEM+ fields. For students who intend to enter graduate school in a STEM field or for those who plan to work as laboratory technicians, a mentored research experience in a research laboratory is essential. For students who intend to enter medical school or other health professions programs, a mentored research experience is also very helpful. Students who work in research laboratories gain connections to additional mentors who are working at an advanced level in the field as well as near-peer and peer connections with post-doctoral scholars, graduate students, and other undergraduates who are part of the lab group. The apprenticeship model, in which trainees learn by doing under the guidance of more experienced individuals, is an important part of the laddered mentoring that takes place in research settings. Mentored research laboratory experiences provide students with developmentally-appropriate ways to apply their knowledge and advance beyond rote recall to pose insightful questions that highlight areas for future experimentation, thereby establishing their identities as scientists and investigators. Students who work in research laboratories gain a deeper understanding of the STEM fields that can help them to build strong connections between the material covered in the undergraduate curriculum and the state-of-the-art in their disciplines through immersion in reading salient papers in the area of the research. The greater familiarity with the research literature and the broader connections to disciplinary curriculum that emerge through participation in mentored undergraduate research can result in improved undergraduate grades (Sell, Naginey, Stanton, 2018) and improved performance on the entrance examinations for graduate and health professional schools such as the MCAT (Steed, K.S., Kadavakollu, S, 2019) and DAT (American Dental Association, 2021), which utilize passages that resemble research reports that must be perused quickly with high comprehension for successful outcomes. The current version of the MCAT specifically seeks to assess four scientific inquiry and reasoning skills (AAMC, 2021) that can be strengthened through research experiences. In addition to building skills in analytical and critical thinking, research laboratory experiences build skills in professionalism, collaboration, and networking. These skills are important for personal as well as academic growth and help to build maturity, poise, resilience, and adaptability. For many students who have unclear career goals, a mentored research experience can help them to realize their passions for discovery and solidify their interests in research careers. These insights can provide important motivation to persist in their studies in the face of challenges, setbacks, or doubts. In some cases, the excitement of discovery and research may lead some students to change from their initial career goals of becoming clinical practitioners to pursuing careers as research scientists.

Mentored undergraduate research opportunities are important for all students, but may be particularly valuable for diverse populations of underrepresented students. Many of these students have had limited prior exposure to research and have never considered the possibility of a career in STEM research. High school guidance counselors and family members may have encouraged the single-minded pursuit of a career as a physician. Often, these influential adults are unaware of the opportunities that careers in research offer, so they do not mention this career option to students who are interested in one or more of the STEM fields. Many undergraduate students are also not aware that the costs of doctoral education in the STEM fields are usually not the responsibility of students, in contrast to the substantial costs that are borne by students pursuing degrees in the health professions. As a result, many talented underrepresented students never consider careers in STEM research. However, the U.S. scientific enterprise depends upon a diverse STEM research workforce; mentored undergraduate research experiences allow students to find out whether careers in research will satisfy their personal and professional goals and provide opportunities to connect with mentors who can foster their connections to graduate school advisors if they discover that this a path that they wish to pursue.

When research laboratories offer mentored research experiences to undergraduate students, particularly for those from underrepresented backgrounds, significant benefits accrue to the host laboratories. The undergraduate research students can bring diverse perspectives and new insights into the lab group, thereby helping the more senior members of the group to appreciate a broader variety of lived experiences, cultures, and means of communication. These new insights can lead to new avenues of inquiry and new means of disseminating research findings to the scientific community and the public, including social media, blogs, vlogs, and podcasts. In addition, individual laboratory members will have a learning opportunity through mentoring undergraduate students and will experience the satisfaction of diversifying the STEM+ workforce as well as contributing to the reduction of educational disparities and broader societal inequities.

Substantial enhancement of the diversity of the STEM+ fields is dependent upon investments to create a significant number of mentored undergraduate research opportunities for diverse populations of underrepresented students. Funding for this crucial purpose may come from federal, state, foundation, corporate, or philanthropic sources. In particular, a major investment from governmental sources seems essential and appropriate to this vital national and societal priority. However, it is also essential for laboratories which typically have little direct contact with undergraduate students, such as those in stand-alone medical centers, research institutes, national laboratories, and corporate sector facilities, to create mentored research opportunities by establishing partnerships with nearby colleges and universities to support and promote student participation. Many students from underrepresented and/or socioeconomically disadvantaged backgrounds are enrolled in two-year and teaching-focused four-year institutions, so they may lack access to mentored research experiences on their own campuses. As such, it is crucial for neighboring research institutions to provide these much-needed opportunities. There are relatively few research universities with high levels of enrollment of underrepresented students, but these institutions should be a natural nexus for investments to fund mentored research experiences for diverse undergraduates.

Recommendations

One of our underlying theses is that mentoring provides a crucial advantage to promote student success, and perhaps especially so for students who are first-generation university students or those who come from educationally or socioeconomically disadvantaged backgrounds. In order to provide a more welcoming and inclusive environment, and to promote greater success for students from every background, we offer the following recommendations:

1. Mentoring must be brought to scale through clearly articulated institutional and disciplinary prioritization of learning communities, with attendant assessment to monitor the impact of creating an environment that supports diverse students from underrepresented backgrounds.

2. Individual faculty members and principal investigators affiliated with academic institutions and stand-alone research facilities can, by embracing their mentoring roles, play a crucial role. By forming partnerships with nearby institutions, they

can provide essential mentored laboratory experiences and thereby promote the diversity of the STEM+ workforce.

3. Faculty members, administrators, and staff members must commit themselves to the success of **each** student who enrolls in a STEM+ program. Many students enroll in these programs with great hopes and dreams, often carrying with them the hopes of their loved ones for a better life in the future. Gateway courses, in particular, should strive for the success of **every** student, rather than accepting high rates of failure as inevitable.

4. Apprenticeship learning is the dominant pedagogical modality in STEM+ fields, but it is not used commonly in the introductory STEM coursework. Increased interactions between first-year students and faculty members through experiences that promote authentic engagement and discovery are key to promoting the retention of diverse populations of students who are underrepresented in the STEM+ fields. Mentored learning communities can effectively foster such interactions.

5. Learning communities can amplify the impact of an individual mentor. All students who express an interest in a particular STEM+ course of study should be intentionally placed in settings where they can form connections with peers and a mentor. Many students who “wash out” of the STEM+ fields do so without ever meeting a mentor or feeling as if they were individually known and supported. Seminar-based learning communities can also be tailored for students who do intend to major in a STEM+ field; a mentored and supportive learning community experience may encourage some students to enter these fields.

6. Barriers to student success, such as weak preparation from high school courses, must be proactively and effectively addressed. Ideally, students who are likely to have weak backgrounds can be identified before classes begin and they can be offered opportunities to strengthen their foundational knowledge prior to matriculation.

Authors’ Addendum

Given the special venue in which this article appears and considering that we benefitted from the outstanding mentorship of Professor John B. Little, we wanted to add some personal reflections on our great mentor and how he influenced our approach to mentoring as outlined here.

Dr. Little’s mentoring style emanated directly from his heart and experience. He made sure that students became part of his research family and they had an important role to play in advancing the work of the group. He enjoyed introducing members of the lab to his wife, Françoise, and sons Frédéric and John. He held regular social events– at his home, at Radiation Research Society (RRS) meetings, and later at his eponymous annual symposium at the Harvard TH Chan School of Public Health– and graciously introduced lab alumni to students. Students learned that they were a part of a distinguished lab lineage of more than 250 people. He created a community environment, where people who never overlapped in the lab, or in some cases were never members of the lab, were drawn together by their shared affinity for Dr. Little.

Indeed, this manuscript is a testament to the power and strength of the intergenerational community that Dr. Little always sought to foster. Although he was always busy at RRS conferences, he made sure to introduce us to one another. Whether he could foretell the similarities in our eventual career paths or felt that we were kindred spirits with respect to our responses to his mentoring, we both remember that, with a sense of great joy and pride, he introduced his last graduate student (CAR) to a much earlier member of his extended lab family (AJG).

Dr. Little was exceptionally humble and accessible, a man of few words who spoke with great clarity and incisiveness. He was always willing to listen to intriguing ideas, even if they came from someone junior who might ordinarily find difficulty in being heard, or if they emerged from counterintuitive results that might typically be set aside. He supported his trainees and stimulated their passion for discovery, even when new findings were challenged since they compelled a reexamination of a prevailing paradigm. As a result, numerous seminal findings emerged from Dr. Little's laboratory. Still, the scale and scope of these impressive achievements rest on a foundation of mentorship and community that Dr. Little was able to create.

Dr. Little's remarkable patience and support led to a large number of successful mentees. While some PIs expect their graduate students and post-docs to investigate questions of central interest to the PI, he wanted his trainees to develop their own research questions and methods. He sought and developed independent thinkers who would challenge accepted paradigms in the radiation sciences and establish new ways of understanding the biological effects of radiation exposure. He allowed students to engage in healthy struggles and flail a bit while offering guidance and raising questions that would help trainees find their own solutions to problems. The lessons that trainees learned from seeking their own solutions to challenges empowered them to forge ahead with their research and motivated them to continue to tackle ever larger research problems. He fostered independence of thought within a collaborative and supportive community.

Dr. Little was also an exceptional mentor because he valued his mentees and his relationships with them. Perhaps the most important expression of this commitment was that he did not try to mold people in his image; to become the next Dr. John B. Little. He enthusiastically celebrated the successes of his alumni who became independent investigators in the field, but he also marveled at the successes of his alumni who pursued careers outside of radiation biology. He always encouraged his mentees to remain engaged in some form of intellectual engagement and leadership, rather than repetitive or derivative day-to-day work. He supported his mentees unconditionally, while in the lab and throughout their careers. We strive to mirror Dr. Little's mentoring approaches in our roles as mentors to high school, undergraduate, and graduate students.

When trainees completed their stay in the laboratory, Dr. Little was unusually effective at remaining in communication with his extensive network of mentees. Trainees were bestowed with a degree and with a permanent place among the hundreds of students, fellows, and post-docs who trained in the laboratory, and dozens of others who collaborated or were influenced by their interactions with Dr. Little. This sense of belonging to a family has led to professional collaborations, leadership positions in professional organizations, and appointments to Federal agencies. Dr. Little was formally recognized as the inaugural recipient of the Radiation Research Society's Excellence in Mentoring award in 2002. The inclusion of this paper on mentoring in the STEM+ fields within this special issue of IJRB is therefore both notable and appropriate. We offer this personal reflection as a small token of gratitude for Dr. Little's guidance, friendship, and support throughout the years.

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