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The importance of local long-duration STEM mentorship as a global mechanism for increasing diversity at all levels of education

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We begin with a brief review of the progress being made by the professional space physics community to increase diversity and inclusion. These efforts have been primarily centered on overcoming barriers that have inhibited existing underrepresented minority space physics professionals from being successful at all levels of academic, mission, and administrative achievement. While we find these remediations to be essential, we must recognize that our ability to achieve a diverse professional workforce representative of the US population depends on achieving a diverse population of researchers entering the field. That means the greatest gains can only be achieved by actions that reach into the educational system. We identify and discuss possible issues within the traditional formal education and developmental environment of young inquiring minds, including gaps in resources, the pressure to bring in income during secondary school and graduate school matriculation, and the cultural biases against research careers. We highlight the importance of local mentorship and age-appropriate research-like activities within all levels of education, including Kindergarten through bachelor's and advanced degree programs, as a means of overcoming barriers to becoming a respected contributing member of the space physics research community. We note these issues extend beyond space physics into all STEM fields. These activities can provide road maps into research careers, practice age-appropriate skills, and provide an avenue for current researchers to become mentors. Specifically, we advocate the development of a formal program of professional chapters for colleges and age-appropriate research-oriented programs for K-12 schools and encourage strong collaborative affiliations with other professional societies. At the core of this is the development and implementation of informed, persistent mentoring.

KEYWORDS
mentoring, diversity, inclusion, K-12 stem, higher education, attrition, leaky pipeline, braided river

1 Introduction

Significant strides are being made within the space physics workforce to improve diversity and inclusion (D&I). Gannon and Lugaz (2020) summarize a NOAA Space Weather End User panel discussion at the 2019 AGU fall meeting, where attendees discussed progress toward increasing diversity and inclusion in the space weather and space physics communities in the United States. The short article made the case that D&I is receiving broad recognition within the American Geophysical Union (AGU) and NASA, but much is yet to be done. Ford et al. (2018) show progress in bringing young women into these fields; however, persistent preference was shown for experienced male scientists for invited oral AGU fall meeting presentations when primary session organizers are male. Basic representation in these fields was shown to be profoundly lacking for African Americans, Hispanics/Latinos, Native Americans, and Pacific Islanders, who used the results of Ford et al. (2019) based on abstract submissions from 2014–2017. These minority ethnic and racial groups comprised only 7.7% of the total submissions, even though they comprise 31% of the United States population.

AGU's Space Physics and Aeronomy section has also taken an active role in addressing D&I. Diversity involving gender, geography, and career-stage has and is being sought for committees, such as the Fellows Committee, as reported by Gannon and Lugaz (2020). Jaynes et al. (2019) report on the work of Dr. Elizabeth MacDonald of NASA Goddard Space Flight Center who, in the fall of 2017, organized the Nomination Task Force within AGU's SPA section to create nomination packages for individuals from underrepresented groups. Three of the six nominated individuals received prestigious awards recognizing their outstanding achievements. One of the effects of implicit bias has previously led to a long-time lack of recognition through professional awards. Keesee et al. (2019) discuss progress and continuing shortfall in D&I through professional recognition by awards and prizes.

Similarly, much effort is ongoing within NASA Headquarters and at all field centers to advance D&I for recognized benefit across all organizational elements captured in the FY 2022–26 NASA Strategic Plan for Diversity, Equity, Inclusion, and Accessibility (DEIA). The effort is strongly represented in the public statement by NASA's Administrator Bill Nelson (2022): "We fully embrace DEIA as a strategic enabler of our safety and mission assurance. Our commonalities unite us as a team, and our differences strengthen our capabilities, including our talent, skills, knowledge, experience, innovation, perspectives, and ideas that optimize performance and mitigate groupthink, optimism and confirmation bias, complacency, normalization of deviance, and risk." Moreover, recent efforts have been made to evaluate DEIA in NASA's Space Mission teams and their Principal Investigators (PI) (NASEM, 2022).

The space physics community has shown a clear commitment toward advancing the goals of D&I and that there continue to exist systemic barriers that discourage advancement. It is vital that our profession continues to minimize the attrition of young researchers by limiting bias in proposal reviews, improving opportunities for professional society positions of responsibility, ensuring more opportunities for prominence at conferences, and removing bias in promotion and tenure. However, it is essential to recognize that our ability to achieve a genuinely diverse professional workforce representative of the United States population depends on maintaining a diverse set of researchers entering the field (Funk et al., 2021).

Estrada et al. (2011) and other works, discussed in Section 2, Section 3, Section 4 find that the broader STEM community falls short of nurturing young minds, failing to enable them to seek betterment, equity and positive reinforcement at all educational levels. While much of that work is narrowly focused on age ranges or specific types of institutions, some published research and active remediation efforts are immediately applicable for consideration. The lost youth from STEM education pathways has become known by the concept of a "leaky pipeline" (Estrada et al., 2011), where a much larger underrepresented population cannot traverse the hardships of socioeconomic and educational environments required to attain researcher status. They are lost from the educational "pipeline" at each step because their parents tell them, "that's not for people like us." They are lost because they visit a campus and do not see anyone like themselves or how they can fit in. They are lost because they have no STEM role model, no way to build self-efficacy, or sense of belonging within the STEM community (Estrada et al., 2011). Most recently Batchelor et al. (2021) has introduced the concept of "braided river" in recognition of the need to dismantle the overly simplistic imagery of a pipeline to instead embrace the many "on-ramps, pathways, and career pivots that real life induces" that the braided river model with its "numerous interwoven and changeable channels capture." The braided river concept fosters flexible and adaptable pathways as each person seeks their way to a STEM career, perhaps through a mentee-mentor relationship.

Both models begin after high school when students traditionally are first faced with making choices for their educational future. We find that the attitudes of many children toward potentially rich STEM careers are lost much earlier and that is where we begin our discussion in Section 2 to establish how children can remain in the braided river through mentoring. We highlight six key strategies that help overcome challenges. Section 3 is all about mentoring as a professionally learned skill that necessarily evolves with its application and a changing society. Section 4 discusses the professional organization's critical role. We conclude by encouraging professional researchers to take steps through their societies to help build an equitable and rich multicultural research environment.

2 The developmental significance and persistent fragility of self-efficacy

Eccles et al. (1983) developed an expectancy-value model of achievement-related choices, as applied to gender differences, in which students' decision on whether or not to continue in the STEM pipeline is determined by their expectations for succession and the relative importance they gave to the available options. Their expectations for success were dependent on their self-beliefs about their ability to succeed, referred to as self-efficacy. Eccles (2009) describes the relative importance to be represented by the subjective task value (STV), the importance of taking mathematics and science course in terms of four elements: (a) the utility value as related to the student's future goals, (b) the intrinsic value, (c) the attainment value (the consistency of mathematics and science with the student's identity), and (d) the cost, such as time taken away from other activities or the negative responses of the student's peers. Each individual assesses their STV based on what they gain from their culture, socializers, and experiences.

Andersen and Thomas (2013) apply the STV model (Eccles, 1983; Eccles et al., 2009) to investigate the plans of ninth-grade underrepresented minority (URM) students. They base their work on the assumption that all students stay in the STEM pipeline by default before high school. Their expectation was those students traverse different coursework or career preparation paths based on perceived ability, motivation, and opportunity, suggesting that this is the critical time for understanding the factors that affect students' plans to persist in STEM. They found that mathematics and science self-efficacy were not significant predictors of persistence plans, apparently because of perceived barriers to opportunities compared to those of white students. Andersen and Thomas (2013) mention the influence of deficits students face in taking advanced preparatory mathematics and science coursework at low-socioeconomic status high schools but acknowledge that it is often attributed to disinterest (Thompson and Lewis, 2005).

However, what appears as disinterest may have become an implanted self-belief or acceptance of the socioeconomic stereotype expressed by parents, peers, or even teachers (Ambady et al., 2001). Ambady et al. (2001) conducted a study involving elementary and middle school children where they activated positive and negative stereotypes for cognitive performance in kindergarten-grade 2, grades 3–5, and 6–8. They found that positive and negative self-relevant stereotypes can affect the performance of even very young children. Asian-American girls in lower elementary schools performed significantly worse than a control when their gender identity was activated and performed significantly better than the control when their ethnic identity was activated. The same-age Asian-American boys performed significantly better when both gender and ethnic identities were activated, also in accordance with stereotypes. The same was true for these groups in middle schools. Ambady et al. (2001) state that both younger and older girls and boys possessing an alternative identity associated with positive stereotypes, such as in math and science, might buffer girls from the negative stereotypes associated with their gender. The same susceptibility and protective buffering ought to be anticipated regarding other common negative stereotypes involving ethnicity, race, religion, or socioeconomic status.

The Ambady et al. (2001) study builds on that of Steele (1997), who more broadly discusses the achievement barriers women and African Americans face in school. These groups are usually identified with socioeconomic domains with negative stereotypes that, when activated, dramatically depress their academic performance. Steele (1997) reported studies from the 1980s–1990s showing that this stereotype threat had led to a crisis for African Americans. By the sixth grade, they had fallen two grade levels behind their white counterparts with whom they had been evenly matched when they started school. Steele (1997) reports a study showing virtually no differences between boys' and girls' performance in standardized math tests through elementary and middle school but trends toward a steady divergence of men over women in high school and beyond, with women leaving math-oriented fields at more than twice the rate as men.

Steele (1997) suggests what they call the "wise" strategy for supporting and guiding students who are stereotype threatened, listing:

1. "Optimistic teacher-student relationships." While stigmatized students worry that other students will doubt their abilities, the authority of potential-affirming adult relationships in a mentoring program provides critical motivating feedback and optimism about their potential.
2. "Challenge over remediation. Giving challenging work to students conveys respect for their potential and shows them they are not regarded through the lens of an ability-demeaning stereotype."
3. "Stressing the expandability of intelligence." Repeatedly advocating the expandability of intelligence to elementary school tutees to significantly improve grades counters the fixed-limitation ability stereotype inherent in one's group.
4. "Affirming domain belongingness. Negative-ability stereotypes raise the threat that one does not belong in the domain." Direct affirmation of their belongingness in the domain is important, and to base this affirmation on the student's intellectual potential.
5. "Valuing multiple perspectives." Explicitly value a variety of approaches to academic substance and the larger academic culture. "Making such a value public tells the stereotype-threatened student that this is an environment in which the stereotype is less likely to be used."
6. "Role models. People from the stereotype-threatened group who have been successful in the domain carry the message that stereotype threat is not an insurmountable barrier."

The generalized mentoring actions are noted in the summaries above and discussed in length by Steele (1997). A mentor, for example, is an authority figure for the mentee so by expressing optimism about the mentee's performance and ability to solve challenging problems the mentor has implemented the first two of the Wise strategies. By consistently showing the mentee respect, by challenging the mentee with increasingly more difficult problems, and listening to their ideas for solutions the mentee is implementing the Wise strategies 3, 4, and 5. By being honest, respectful, consistent, and successful member of the greater STEM community and looking like the mentee a mentor becomes a role model for the mentee and implementer of Wise strategy 6.

3 Sustaining self-efficacy through persistent mentoring

Mentoring is building a focused, intentional relationship between an established community member and someone new to the field. Positive mentoring relationships have been shown to increase the success and retention of students from underrepresented groups and to reduce stress, anxiety, and depression (Hund et al., 2018). A successful mentor is a trusted guide and advocate. In contrast, poor mentoring can lead to increased student stress, attrition, and decreased productivity. Hund et al. (2018) and cited papers also discussed the risk mentors face when they become blind to the power they hold over their mentee.

Hund et al. (2018) conducted a survey where 70% of responding mentors reported they "rarely" mentor poorly, while 39% of all respondents reported poor mentoring "frequently." Of the responding mentors, 69% reported no formal training, and 74% "little" training.

In addition to many available studies, Byars-Winston and Dahlburg (2019), hereafter the Report) declares that "mentorship is a skill that can be developed through intentional and reflective practice and cultural responsiveness." Several institutions have created professional mentor training programs, including through online interactive guides provided by this Committee, which the Report highly recommends.

The Report distills mentoring into two core functions: providing psychosocial support, which includes role modeling, and offering career support, which includes providing challenging work toward skill development. As noted, individualized practices of mentors promote successful extended relationships between mentor and mentee. Psychosocial support may include such things as encouraging problem-solving and active-listening techniques. It may include role modeling involving mentee behavior and professional values. Mentor-mentee interpersonal interactions can allow mentees to see themselves as future academics to the extent that they identify with the mentor. Career guidance can take the form of evaluating the mentee's strengths, weaknesses, and interests. Mentors can help mentees reflect and think critically about their goals, challenge their decisions, and realize their aspirations. Mentors should be trusted to acknowledge the achievements of mentees publicly and be their advocates. A mentor must maintain professional boundaries and ethics, including communication, providing objective feedback, not losing their temper, and respecting their mentee's privacy. Moreover, the mentor and mentee must have a dynamic changing relationship as each needs mature.

Mentoring at the elementary and secondary levels often focuses on the fundamental math and science skills. While mentoring at the undergraduate and graduate levels includes more in-depth discussion and exposure to research and career pathways in STEM fields. The Wildlife Society is one professional organization that is leading the way for students at the college level. They have developed a mentorship program[1], Leadership Institute, Student Development Working Group, and Student Chapters[2]. Lopatto (2007) notes that undergraduates who experience authentic research in the sciences have a positive impact on those pursuing graduate school. NASEM (2022) highlights the importance of mentoring at the graduate student level which is important for the development of diversity in NASA's Space Mission PIs.

1 https://wildlife.org/mentoring/.

2 https://wildlife.org/next-generation/student-benefits/.

4 Mentoring through organizations and professional societies

Barnes et al. (2021) bring attention to the scenario where national societies and "locally-based" institutional undergraduate student chapters provide atmospheres in which underrepresented groups can develop relationships and skills required for academic and professional careers in STEM. These societies and student chapters also combine to contribute to outreach STEM activities. Barnes et al. (2021) state that using underrepresented group (URG) student chapters of professional societies, at the undergraduate level, allows students to become active members of professional organizations while also receiving mentoring, support, and resources (e.g., leadership opportunities, scholarships, internships/jobs, and education opportunities[3]). They allow students to connect with the community directly by contributing student posters at conferences and being part of making a difference locally, for example, through student research internships and STEM outreach. The students also become part of something bigger, a pathway to the scientific world where they can develop leadership and mentorship skills of their own. Student chapters need to be created at primary, intermediate, and secondary levels to aid in slowing loss from the braided river by helping to promote equitable access to resources. The University of New Mexico has a Mentoring Institute which offers an annual conference and training.[4] These go beyond what AGU currently targets connecting professionals with undergraduate and graduate students and Early Career researchers in their Mentoring365 network.[5]

Mentoring can become a skill actively taught and shared as developed and demonstrated. Trained college-age chapter mentors could be incorporated into high school chapter functions. Trained high school chapter mentors could participate in primary and intermediate school chapters. This is ladder mentoring, which could become a new element in this context that would be designed to inspire and provide a supportive space to encourage young students to express their excitement in STEM activities. Trained, young mentors become a role model and consistent, familiar presence with younger mentees while always in the company of a supporting senior certified mentor (the research professional). However it would be implemented in the lower grades (K-12), it would need to be frequent enough to be meaningful but not be an unacceptable burden on those involved. Relatively frequent events for K-12 might become integrated with school science fairs, including sponsorship and judging. Within Regional Student Chapter Associations, Conclaves could be held, like Science Olympiads, which provide STEM field-specific knowledge competitions for junior participants, mentoring by senior professionals, and relationship-building between peers and professionals[6].

There are a lot of ongoing efforts within the STEM community to discuss, highlight, and provide training for D&I (e.g., Lunar Surface Science Workshop, 2022; NASA, 2022). NASA Science Mission Directorate Inclusion Plan Pilot Study requires researchers to specifically address how they will promote and foster inclusion within their teams as a key proposal element. The Planetary Science

3 https://wildlife.org/next-generation/student-benefits/.

4 https://mentor.unm.edu/conference.

5 https://mentoring365.chronus.com/.

6 https://wildlife.org/se-section/about/conclave/.

program, Payloads and Research Investigations on the Surface of the Moon (PRISM) is one of the participating programs (Watkins, Lunar Surface Science Workshop, 2022). More work can be done getting professionals to work on local scales. Moreover, no formal mentoring training currently exists. NASEM (2022) highlights D&I as important for successful teams for NASA Space Missions and their PIs. While formal mentoring training currently exists[7], this training has not become a part of mainstream PhD curriculum and likely needs to become a mandatory element of academic training, as was noted by Reuben (2020), "Scientists are not trained to mentor. That's a problem." Moreover, more work needs to be done getting professionals to work on local scales where large impacts are made.

5 Conclusion

From the beginning, we have established the perspective that fundamental progress toward the meaningful integration of underrepresented members of our society as successfully contributing partners in space physics and other STEM research fields requires our intentional and meaningful involvement in the motivation and self-efficacy of those who would become our partners beginning at a young age. Further, only using persistent and evolving encouragement and training experiences can we anticipate members of historically underrepresented groups to thrive in STEM fields. The scale on which this must occur requires a collective approach, which at a minimum, begins in our professional space physics societies. In truth, it requires strong collaboration and coordination across professional societies to enable a general society-wide awakening of STEM opportunities without socioeconomic borders.

The evidence we have highlighted strongly suggests that the youngest students begin with equal openness to experience everything their world has to offer. They seek to understand who they are, where they belong, and how everything works together. Each step they make will become positive or negative experiences that differentiate their academic expectations. If a students' progress is encouraged, they will build positive self-efficacy in STEM, solidifying the knowledge of potential success should they choose to continue. If a student's progress is discouraged, the opposite occurs, such that self-efficacy devolves, their inability to perform in STEM becomes predetermined, and they become part of the leaky pipeline. It is our perspective that we cannot passively wait and continue as researchers in our field without taking action to mitigate the issues that drive many away from STEM. Here we have discussed mentoring, particularly local long-duration mentoring at the university, and K-12 grades, as one important aspect that space physicists can participate in. Professional training in being an effective mentor can be useful for all, especially for existing mentors without formal training. Mentoring in the K-12 grades is essential to address the leaky pipeline of the STEM workforce. Professional organizations and societies can play an active role in providing mentoring training for professionals and avenues for these professionals to engage students locally with chapters at the university and K-12 grade levels.

Our past efforts to retain young women, African Americans, Hispanics/Latinos, Native Americans, Pacific Islanders, and other under-represented professionals from leaving space physics have come at the end of a leaky pipeline. A much larger population of potentially valuable contributing individuals were lost, not because they failed to have the intrinsic ability or interest, but because they felt out of place in the STEM world. There are D&I professional organizations with missions to provide safe environments for young under-represented students to thrive. Scientific societies are already working with those societies to integrate STEM themes into those environments. These efforts are experiential and mentor based. Our advocacy is for a strategy based within AGU to actively develop and/or promote mentor training in affiliated graduate programs, to include formal mentor rolls for graduate teaching assistants in their department programs. Next to broaden AGU's efforts to, where possible, coordinate with other professional societies to create college STEM chapters. From these chapters to adopt, foster, or create as necessary K-12 activities that routinely inspire, challenge, and guide young minds that seek a future in STEM. This can be a braided river framework that is built from within and sustaining. One where we can individually find worthwhile roles and contribute if we choose, from the local to the national level Eby et al., 2008.

7 https://mentor.unm.edu/conference.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

SD wrote the initial abstract and authored the concept of the vision for mentoring societies. Also, SD provided much of the literature and contributed to the writing and editing of the text. HH contributed to the writing, editing, and concepts presented. DG authored much of the original text and review of the literature and is the corresponding author.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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