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RESEARCH ARTICLE

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Structures of becoming: The who, what, and how of holistic science advising

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Abstract

Addressing equity issues in science education requires a reorientation to how science students are advised and how science, technology, engineering, and mathematics (STEM) education, particularly science, is viewed. STEM education is often figuratively described as a pipeline containing students who *leak* out before reaching the nexus of their STEM education/career journey. The authors of this paper argue that STEM education must be viewed from an ecosystems perspective, where students interact with one another, their physical environment and cultural contexts, and other humans who can support them in becoming STEM professionals. Within this STEM ecosystem, many individuals have a pivotal role in supporting students as they learn and develop within the science field. These individuals, particularly advisors, must possess knowledge, beliefs, skills, and dispositions that help students cultivate a sense of belonging, engage them in critical thinking about their academic and career choices, and aid their identity development in learning as becoming in STEM professions. The authors describe who these individuals are, the roles they play, and also provide practical examples, using vignettes, of how advisors can support students of color pursuing science degrees and careers. Finally, recognizing that students' STEM advising ecosystem operates at any grade level or stage of life, the authors have organized the descriptive portion of this study according to the following levels elementary, secondary, undergraduate, graduate, and career.

KEYWORDS
advising, equity, science education, STEM ecosystem

1 | INTRODUCTION

Re-envisioning science education through an equity-centered lens necessitates a reorientation of the who, what, and how of advising in science education. Thus far, on the topic of advisement in science education, our paper series has examined the existing literature to describe and critique approaches to advising across P-20 (Beatty & Suárez, 2022) and reimagined the possibilities of approaching science advising from a holistic perspective (Morton & McKinney de Royston, 2022), specifically using Phenomenological Variant Ecological Systems Theory (PVEST, M. Spencer et al., 1997) and Critical Race Theory (CRT, G. Ladson-Billings & Tate, 2006) as organizing tools to imagine a critical-ecological approach. This paper describes the who, what, and how of science advising. In our depiction of what this reimagined science advising could and should look like, we begin by describing the structure or context in which science advising, teaching, and learning occurs, followed by a discussion of the conception of who serves as an advisor and the roles they both currently play and might play in an ecological system. Next, we highlight practical approaches advisors can use to assist students in thinking critically about their academic and career choices while cultivating and maintaining positive relationships that contribute to students' identity development—or their *becoming* and sense of belonging in science (Beatty & Suárez, 2022; Morton & McKinney de Royston, 2022).

2 | REFRAMING THE STRUCTURE: FROM PIPELINE TO ECOSYSTEM

Science, technology, engineering, and mathematics (STEM) education is often described, metaphorically, as a pipeline with students entering STEM disciplines and majors and exiting at the other end into STEM careers. This metaphor and visual representation, as shown in Figures 1 and 2, is used to explain or identify: (a) the low number of people entering STEM fields compared to the large number of high school students who potentially enter the pipeline (Cannady et al., 2014), (b) the lack of diversity, in terms of women and Black, Indigenous, and People of Color (BIPOC), in STEM professions, and (c) "leaks" in the pipeline where students leave STEM.

The STEM pipeline argument has been used to justify a wide range of grant initiatives, policies, and programmes that aim to *broaden participation* while specifically targeting populations underrepresented in STEM in an effort to increase the number and diversity of STEM professionals (Cannady et al., 2014). However, this overly simplistic and unidirectional (Shackley, 2020) view of the STEM education pathways into STEM professions fails to account for the complexity of cultural contexts that support an individual's affinity toward and persistence in STEM disciplines or professions. Also, the pipeline metaphor does not account for the interplay of culture and identity of

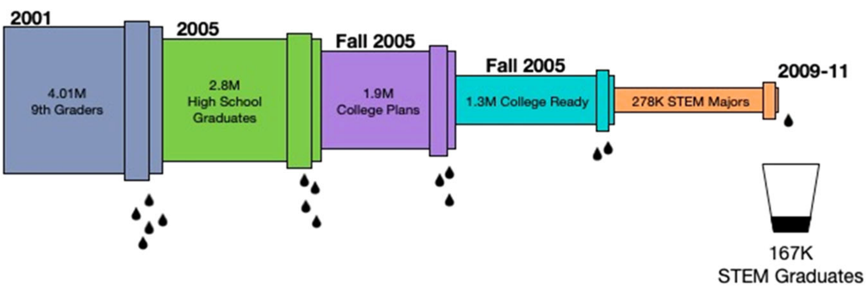

FIGURE 1 Visual representation of the science, technology, engineering, and mathematics pipeline (based on Arens, 2015).

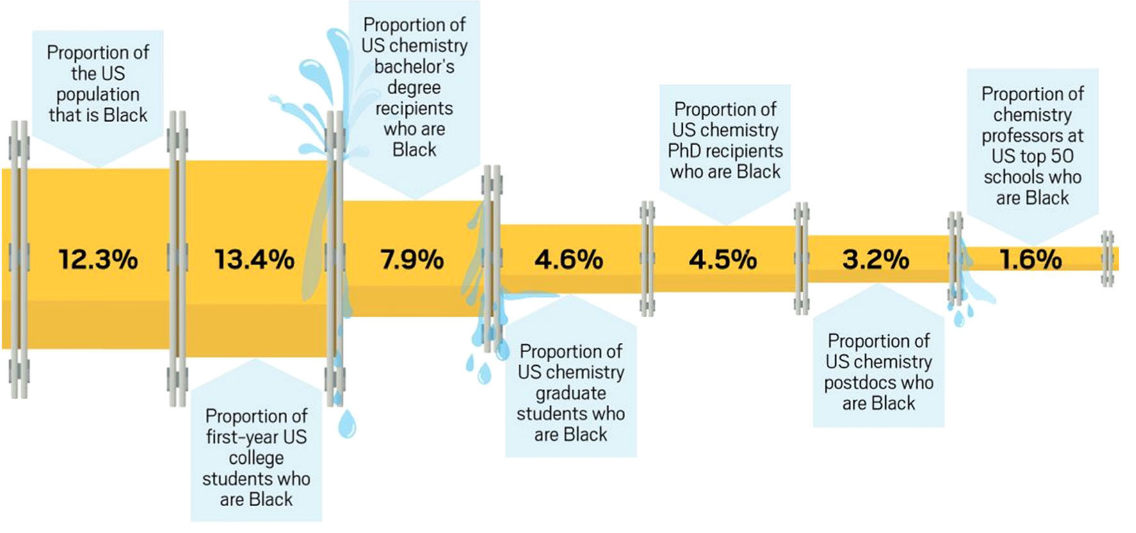

FIGURE 2 Visual representation of the leaky pipeline for Black chemists (https://cen.acs.org/careers/diversity/leaky-pipeline-Black-chemists/98/i22).

the students or science (Shackley, 2020). As Aikenhead (1996) and others asserted, science as a field has a culture that is modeled and shaped by Western White culture. Students, as Shackley (2020) posited, bring their already formed identity into the science classroom, and it is continuously shaped as they interact with one another and the science content. Thus, failing to acknowledge students' culture and the sometimes conflicting culture of science creates missed opportunities to explore more deeply the issues that contribute to BIPOC students' decision-making around persisting or exiting science.

While the use of the STEM pipeline illustrates the trends in STEM enrollment and persistence over time, it does not unpack the nuances related to why BIPOC leaves STEM disciplines and careers or how the culture of science disrupts students' sense of belonging in the field. The pipeline metaphor has allowed policymakers and researchers to focus funding and their attention on "… patch[ing] the leak" (Cannady et al., 2014; p. 444) by implementing interventions focused on arbitrary points where students are perceived to leave the system instead of examining the systems and structures within science that function as obstacles or barriers for BIPOC students. This linear focus on a path through specific timepoints misses the rich complexity of personal and cultural influences on individual students as they navigate their lives and the choices about their emerging identity. Thus, what we are arguing in this paper is that we—science educators broadly speaking—must take a more holistic and ecological view of our students, the STEM fields, and the complex relationship between the multiple cultural contexts. To do "[d]isrupt harmful institutional practices and learning spaces that perpetuate structural racism or gendered racism" (Morton & McKinney de Royston, 2022), two shifts in our conceptions of advising are critical—from advising as a linear process with a limited number of actors (i.e., officially sanctioned/recognized advisors) to advising as communal and ecological with many actors and from seeing advising as being about STEM attitudes and competencies to advising the whole student in a responsive and culturally competent way.

2.1 | Toward a holistic ecological view of science education

In an attempt to recognize the relationship between students' culture and the culture of science, Shackley's (2020) suggests a bidirectional pipeline wherein students' funds of knowledge (Moll et al., 1992) drive the science learning, but in turn, the science knowledge learned is used by the students within their communities. This brings nuance to the pipeline argument but remains focused on a single linear dimension of knowledge and retains the focus on individual students' interactions with the culture of science. We argue for a holistic view of movement into the science field as learning as becoming, which requires a shift from the pipeline metaphor to a rich community ecosystems perspective that accounts for the students' cultural contexts (Spencer et al., 1997), including the multidirectional movement of knowledge through construction and use. Students of color pursuing science degrees and or who are professionals in the field are not isolated. They are surrounded by influencers—such as family members, teachers, advisors, and peers—who can directly impact their ever-evolving science identity and STEM educational experiences (Figure 3). Furthermore, the antiquated pipeline metaphor does not account for the students' cultural context, which may play a role in students' motivation to enter and persist in the sciences. Nor does this model account for students' decision-making and responses to negative and positive experiences in sciences.

2.2 | Who advises?

Moving to an ecological focus in advising, we need to see advisors as the people who influence young people's identity development with regard to becoming in STEM and their larger/holistic selves. Advising can take occur in many places and in many ways. Conversations in the barbershop contribute, as do visits to science museums, influential artists or media personalities, and of course, teachers and counselors in schools. Advising can be seen as a web of social and cultural connections that influence the nature of a child's becoming? These diverse communities in a child's home and school life both contribute to their identity development and are changed by the knowing child as they move between communities as a boundary crosser. It takes a village, but the child is agentic in defining the nature of their village.

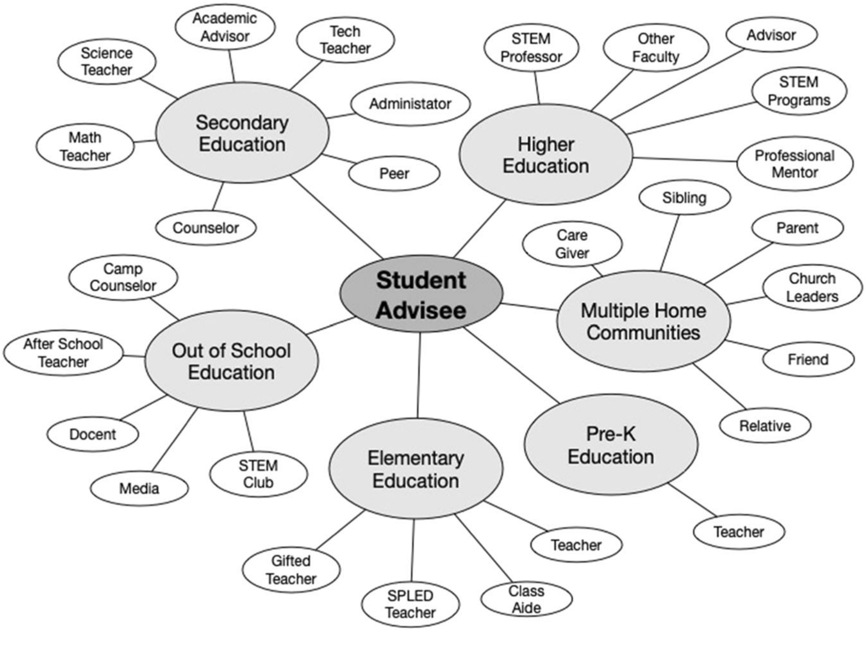

FIGURE 3 Some of the communities and actors that play a role in science, technology, engineering, and mathematics advising in an ecological view.

The first and most obvious actors in the advising ecosystem are the child's parents or other caregivers. The child's family, and the cultural context they define, are central to who the child becomes. However, there are many actors in children's home communities that advise in ways that shape their identity—church leaders, relatives, community leaders, local business owners, and local STEM role models—to name a few. The impact on children in terms of STEM identity is in the way that community members talk about science or science fields, how they view the relevant STEM professions, but also how they see themselves and their children relative to the White supremacist systems that include science. Students of color, in particular, are immersed in issues of authority and oppression, and science plays a crucial role in shaping the power of authority in all the systems they encounter. One of the main ways children are forced to negotiate systemic racism is through their interactions with the school system(s).

There are many different institutional levels to the educational systems students negotiate, as well as the fact that the institutions they are in change over time, both physically and in terms of their focus with regard to the becoming of the children that are now students. In prekindergarten contexts, there is little, if any, explicit focus on STEM concepts/practices, and teachers focus on developing foundational competencies, including social and emotional capacities. Teachers tend to view their role as more supporting more holistic development at this stage, and as a result, there is less focus on a students' trajectory, especially with regard to professional or academic outcomes, including STEM.

Elementary school begins a gradual transition both in terms of the increasing number of actors in the child's ecosystem and also with regard to the increasing focus of the educational system on academic outcomes and the beginning of STEM concepts and practices. Some elementary schools teach science in grades as early as kindergarten, though often it is ignored as a subject until upper elementary grades, that is, third–fifth grades. There also may be a designated science teacher specialist who teaches science to all students as a special class, much like music and art are typically treated. In addition to the classroom teacher, now you begin to have special education teachers, gifted and talented teachers, as well as teachers in relevant specials, such as technology education. There is often a counselor specifically charged with supporting students, though the focus is largely on social–emotional issues rather than on academic planning. Also, at this age, students begin to access STEM-focused out of school activities, like camps, afterschool programmes, visits to science museums, and the influence of media produced for them via video/television (e.g., Dora the Explorer or Magic Schoolbus) and social media (e.g., Youtube channels like SciShow Kids or Mystery Doug). This increases the complexity of the potential advising ecosystem and begins explicit STEM identity becoming for students.

Secondary school, including middle and high school, again adds actors to the advising ecosystem and increases STEM-specific opportunities that can be both positive or negative relative to students' developing identities. Advising actors become increasingly specific in their roles, with teachers differentiated by subject (e.g., Physics, Math, Chemistry, etc.) and counselors being split between academic and social–emotional support, with the latter increasingly being focused on "at-risk" or other students identified as having school or home challenges that are deemed to require special attention. Distinctions between "successful" STEM students and other students become more explicit, with tracking of students by "ability" into honors, Advanced Placement courses, or Dual Enrollment STEM coursework. This controls who has access to the cultural contexts of science and ascribes recognition about who are STEM-able students. Students have access to clubs and afterschool activities that increasingly have academic foci, including math, science, computer science, or technology, like robotics. It is also the case that students may enroll in whole schools with an explicit STEM focus such as STEM academies or magnet schools in large districts, which may be selective (cf. Means et al., 2017). While traditional forms of media may play a role with secondary students, it tends to be social media that most impacts their views of themselves as potential science people. This age, especially the middle school years, is regularly identified as a critical area where students, especially girls and BIPOC students, are alienated from STEM opportunities and/or identities, and in the traditional parlance "leak" out of the pipeline.

2.3 | Institutions of higher education and advising

2.3.1 | Vignette 1: Undergraduate advising

Neil Darden was an outstanding undergraduate chemistry student and was chosen for a prestigious undergraduate fellowship program that mentored underrepresented students toward the pursuit of doctoral degrees. He was the first person in his family to attend college and had not even considered the possibility of a doctoral degree before his acceptance into the fellowship program. As he moved into his doctoral program at his new institution, he felt unmoored, as if he did not know many of the intricacies of academia or even of a White-collar work environment. During one of his weekly meetings with his doctoral advisor, he mentioned the challenges he was facing. Gradually, over the course of the semester, she opened up her home and her life to Neil, allowing him to see firsthand how she lived, worked, and played. Neil's advisor advised him as a complete person and provided space and opportunity for him to envision himself and his career in academia. The advisor and her husband became something of a second family to Neil in time.

The final structure/community in the advising ecosystem is higher education institutions, both undergraduate and graduate programmes. At this point in students' trajectories, they have likely self-identified, or the system has identified them, as STEM-belonging or not. This means the students that STEM advisors in this part of the ecosystem influence tend to be those who are in STEM fields or STEM-related programmes designed to support BIPOC students, such as the McNair Fellows program. Advisors (those formally identified as such) are typically discipline-specific faculty, and their role gradually shifts toward one of mentoring, especially as students transition into graduate work. Students have academic advisors, but they typically aid only in course selection and do little of the support work students require. Increasingly, peers or near peers play significant roles as advisors which include classmates, more advanced students, teaching assistants, or postdoctoral scholars. Also, students are increasingly connected to professional peers in their field from other institutions via conferences or other professional contexts. This marks a phase of transition into the workplace and STEM careers, where advising becomes very individualized and often more holistic but still largely focused on academic and career success. Often the relationships established during this period, like Neil's in the vignette, are enduring into students' professional careers, with deep connections to mentors and peers established as the foundation of the professional community.

2.3.2 | Vignette 2: Near peer and advanced students as advisors

After establishing herself in engineering and becoming a full professor, Dr. Ashley decided to expand her research lab to include undergraduate engineering majors. While she mainly worked with graduate students and postdoctoral fellows, she thought it would be great to structure her lab to give undergraduate students research experiences and prepare them for graduate school. Using her NSF postdoctoral mentoring plan as a template, she designed an undergraduate research mentoring plan that included pairing the undergraduate research assistant with a postdoctoral fellow, monthly research assistant meetings, and monthly work sessions where she provided one-on-one support to the undergraduate research assistant with their research projects. An unanticipated outcome of this mentoring structure was the postdoctoral fellows serving as de facto advisors to the undergraduate students. The postdoctoral fellows shared their research experiences with the undergraduate research assistant and helped them think through different graduate programmes. In some instances, she supported their course selection and listened to their concerns about their experiences.

When opening the notion of advising to a broader set of actors, it is easier to see the influence of many actors from various communities on the identities and STEM identity of students. Even though the titles/roles may change over time, each of these key players needs to recognize their part in the ecosystem and engage students in critical thinking about academic choices and career planning, build relationships with students, and actively assist with students' becoming. Like teachers or professors, advisors are uniquely positioned to provide support or erect barriers to students' development. BIPOC students oft-times do not see themselves in science fields, so advising across their academic trajectory is paramount. Their advisors often become long-serving mentors who provide lifelong guidance and are deep, caring, and supportive in relationships. Therefore, what the advisors know, value, and believe about their advisees—and what they understand about the cultural context of science and their advisees—are essential to their adequately advising BIPOC in science fields and supporting their "self-determined notions of success over their life course" (Morton & McKinney de Royston, 2022). Additionally, what advisors believe about themselves and others, how knowledge is created and recreated, and social relations (G. Ladson-Billings, 1990) have implications for how they interact with, engage and support their advisees.

While the role of an advisor is not to formally deliver content, they do have a role in engaging with students in ways that edifies their academic experience(s). Like teachers, they must possess particular conceptions of knowledge, social relations, and self and others (G. Ladson-Billings, 1990). In other words, they must be culturally relevant advisors who can help students chart a pathway to academic success, leverage students' culture and their own to support students, and have a critical consciousness toward science and science education as distinctive cultures. While all three of these tenets of culturally relevant pedagogy are important, we will focus on the dispositional nature of being culturally relevant and the importance of critical consciousness. Not because these are more important, but instead, they are most pertinent to the role and work of science advisors working with BIPOC students.

3 | CULTURALLY RELEVANT/COMPETENT ADVISORS

The model we are advancing not only replaces the pipeline metaphor, but it also rests on the notion of intersubjectivity wherein individuals "… experience the world with and through others" (Spencer, 2007, p. 697) and serves as a robust framework for thinking about science education, and advisement and its role in students' becoming in particular. Thus, this phenomenological and ecological perspective of the science field is framed by M. B. Spencer's (2007) phenomenological variant of ecological systems theory, which is described as

> … a dynamic and recursive framework that … encourage[s] the critical analysis of human development process … [by] combin[ing] social-cognition linked perceptions with unavoidable context features, and acknowledge the critical role of coping processes in identity formulation and affords a way to frame context-linked life-course experiences and explain patterned outcomes for diverse humans. (p. 698)

Thus, BIPOC students engaged in the learning or doing of science are not moving through a neutral pipeline devoid of culture or context. Instead, they are immersed in communities that have values, norms, beliefs, and rules of engagement that are—at times—in conflict or competition with their own culture and cultural contexts. This conflict may generate risk factors for students with a high net vulnerability due to their race, ethnicity, and/or socioeconomic status (Morton & Parsons, 2018). In this high net vulnerability space, advisors in a students' ecosystem—be they formal or informal—can be risk contributors or protective factors. As risk factors become challenges whereby BIPOC students' net stress increases, advisors can further exacerbate challenges or provide social support to reduce stress. For BIPOC students, we argue that advisors must adopt "a culturally competen[t] and nonstereotyping … orientation [that] functions as a source of support for students" (Spencer, 2007, p. 71). However, a set of practical questions loom: what does it mean for advisors to be culturally competent, what dispositions must they possess, and what behaviors must they enact to serve as social supports for BIPOC students?

4 | CRITICAL CONSCIOUSNESS

4.1 | Vignette 3: Advising through patriarchy and White supremacy

Azaria had come across Maryann Skye through various work she had done before graduate school. Maryann was a senior scholar with an international reputation doing work in informal science, and Azaria worked more in school science, however, she took Azaria under her wing. They bonded in part because they had shared a mentor in the science education world. Maryann believed in Azaria and found venues to uplift her ideas and include her in her projects and professional opportunities (even though she did not have to). She believed in Azaria and created a space where she belonged and helped her carve out her own academic identity. As a woman of color, Azaria was generally given the message that she was the “support,” not the lead on projects, but Maryann helped her retell that story. They also bonded and swapped stories about the patriarchy and surviving/thriving in science education. Azaria appreciated Maryann's vulnerability and was shocked at what had happened to her. Some of the same gender injustices (intersected with White supremacy) still happening to Azaria and those in her generation. Maryann and Azaria's advisors would have meetings of the minds (as elders) to talk about who they would uplift and support as the “next generation” of scholars/researchers/changemakers. To them, it was all about opening doors and creating additional pathways so more could get through and thrive. Over the years, Azaria has considered Maryann a mentor and seeks her out for advice navigating the early career years. Maryann did not have to invest time in Azaria—she chose to—and that has made all the difference.

Science advisors in the broad ecosystem must understand the ways in which race and racism are endemic in American society (Bell, 1992) and how it permeates all American institutions, particularly science. As such, advisors must be aware of the culture of power (Jones & Donaldson, 2022) that permeates science education and manifests in ways that marginalize students of color. They must possess what Lee (2018) calls a “… a consciousness of the ways race and racism influence … the experiences of students of color” (p. 77). The consciousness Lee (2018) refers to is akin to G. Ladson-Billings (2009) critical consciousness, one tenet of culturally relevant pedagogy. Ladson-Billings describes critical consciousness as a teachers' understanding of the larger sociopolitical context in which schooling, and life in general, occurs and engaging students in the critique of cultural norms, institutions, and systems “… that produce and maintain social inequities” (1995, p. 162). Like teachers, advisors must possess this critical consciousness. An advisor who knows and understands the larger socio-political context and recognizes that advising is not a race-neutral space will prioritize the experiences of students of color (Lee, 2018) and can help them develop this critical consciousness, which encourages them to engage the world and others critically.

5 | SHIFTING THE SCIENCE ADVISING PARADIGM

The influence of the STEM pipeline metaphor is widely seen in science education and as previously mentioned, is driving research and policy decision-making in the field. Even within science advising, efforts to recruit and maintain students of color and develop intervention programmes in science reflect the idea of a pipeline that hemorrhages students of color. Yet these interventions and approaches to advising, as Beatty and Suárez (2022) and Morton and McKinney de Royston (2022) suggested, are missing the whole child perspective. An ecological approach to advising forwards the whole-child view and acknowledges the intersubjectivity of learning, making the cultural context a valuable and worthy unit of analysis as we strive to understand how students of color make meaning of their experiences, they engage in science learning and develop a scientific identity. Within this science learning ecosystem, there are influencers who are pivotal in developing students of color as science learners and eventually professionals, but we will not identify these advisors in the ecosystem if we continue to view students as flowing through a linear system.

5.1 | Structures of becoming—Building the holistic advising ecosystem

5.1.1 | Vignette 4: An unexpected advisor

The monthly department meeting wrapped up, and Connie, the department administrative assistant, noticed Sarah remained in the conference room with her head in her hands. Tapping gently on the table, Connie got Sarah's attention and asked if everything was okay. Sarah shook her head no, and Connie said, "Come on, let's go grab some coffee." The two gathered up their belongings and headed to the campus cafe. During their coffee break, Sarah shared, with Connie, her frustrations. Dr. Sarah Ashley, a junior faculty member, has been in the Engineering department for 2 years. She arrived after completing a 2-year postdoctoral fellowship with a premiere engineering scholar. She had established and was carrying out her robust research agenda and had recently become the most cited junior faculty in the department. However, Sarah felt like she was burning the candle at both ends, and despite publishing foundational work in the field that everyone was citing, her male colleagues in the department often overtalked her, rephrased her ideas as their own, and excluded her from collaborative projects. Sarah was starting to feel like she did not belong in the department, and despite being recognized as an up-and-coming scholar in the field, she felt like her work was not good enough. Connie listened closely and gave Sarah the room she needed to talk about her experiences. Occasionally, Connie would ask Sarah about her experiences at work. After that coffee break, Connie often offered Sarah the space she needed to process the gender-based microaggressions. While Connie couldn't provide advice related to Sarah's research, she certainly helped her better understand how to interact with her male colleagues in ways that allowed her to assert herself and feel heard during department meetings.

To open up our notions of advising to recognized and develop ecosystems that can support students becoming STEM individuals, we have to view advising as crossing traditional boundaries of actors' roles, their institutional contexts, and the growth trajectory of students from P-20. While there are identifiable niches in this ecosystem (e.g., elementary schools, afterschool science programmes, graduate programmes in science), and the actors (e.g., teachers, advisors, and parents), they must all be seen as an interconnected and dynamically interacting whole. The temporal pattern for advising across the lifespan can be seen as an increasing and then decreasing set of actors, where initially, in their early life, students' parents/caregivers and home communities are foundational and consistent sources of support for becoming. Then as students move through the institutional systems of schooling, the number and role diversity of potential advisors increases well into undergraduate study, until near the end of the trajectory, in graduate school, it returns to just a few. This pattern can guide us in thinking about where institutions need the most support in coordinating between members of the advising community, and what kinds of structures might be designed to strengthen the entire ecosystem, that is, make it healthier, and how those structures should both change, from the point-of-view of the student, and be interconnected, from the point-of-view of the institutions.

Additionally, the advising ecosystem must become culturally relevant and work toward developing the critical consciousness of a much broader group of role actors than just the identified advisors. By attending to a larger set of potential advisors, both formal and informal, there are possibilities for BIPOC students who are becoming in STEM to be supported in a variety of ways, much like Connie does for Sarah in vignette four above. Intentionally expanding the advisory ecosystem when considering interventions that might increase BIPOC student participation in STEM can build a foundation of rightful presence (Calabrese Barton & Tan, 2019) through early experiences both in and out of school. This change in advising can only occur through a focus on "collective social-cultural-structural transformative action and change" (Morton & McKinney de Royston, 2022) and reimagining what should be.

This section focused on the details of the interrelated niches that make up the ecosystem of STEM becoming, laying out key challenges and potential structures that might be leveraged in meeting these challenges. In addition, this paper built upon Morton and McKinney de Royston's (2022) four guiding principles for taking a PVEST approach to advising in P-20 + STEM education to illustrate possible examples of what this type of advising could look like. We do not intend for the ideas expressed in this paper to be overly prescriptive, but more of a guide that can provide insight for thinking across and be adapted to particular institutional contexts that STEM students encounter along their journey of becoming.

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DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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