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Humanizing STEM education: an ecological systems framework for educating the whole student

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STEM higher education in the U.S. has long been an uninviting space for minoritized individuals, particularly women, persons of color, and international students and scholars. In recent years, the contemporary realities of a global pandemic, sociopolitical divides, and heightened racial tensions, along with elevated levels of mental illness and emotional distress among college students, have intensified the need for an undergraduate STEM education culture *and* climate that recognizes and values the humanity of our students. The purpose of this article is to advance a more humanized undergraduate STEM education and to provide a framework to guide efforts toward achieving that vision. We argue that humanizing approaches recognize and value the complexity of individuals and the cultural capital that they bring to their education, and that this is particularly important for empowering minoritized students who are subordinated in status in STEM higher education. A STEM education that centers students' humanity gives rise to equity and promotes human well-being and flourishing alongside knowledge acquisition and skill development. We then offer a guiding framework for conceptualizing the broader ecosystem in which undergraduate STEM students are embedded, and use it to outline the individual and collective roles that different stakeholders in the ecosystem can play in humanizing STEM education.

KEYWORDS

STEM education, undergraduate, humanizing, student, ecological model

Introduction

The culture of science, technology, engineering, and math (STEM) disciplines has historically been critiqued as being inhospitable and hostile, especially toward White women, racially minoritized students, and students with minoritized identities of sexuality and/or gender (Miller et al., 2021; National Center for Science and Engineering Statistics, 2021). Perhaps this is because STEM fields are "designed to attract White men who are heterosexual, abled-bodied, Christian or atheist, middle-class and above" (McGee, 2020, p. 634). From creating a chilly climate toward women in STEM (e.g., Beede et al., 2011; Jorstad et al., 2017) to perpetuating institutional racism (e.g., McGee, 2020; McGee et al., 2021), current STEM culture is an uninviting space for many students and faculty (Allen, 2017; McGee, 2020). In addition, students who identify as LGBTQ+ must navigate anti-LGBTQ+ discourses, hypermasculinity, and invisibility in their STEM communities (Cech and Waidzunas, 2021; Miller et al., 2021).

Thus, it should be little surprise that White women and minoritized students are consistently underrepresented in undergraduate STEM education and the STEM workforce when compared proportionally to overall population numbers in the United States (National Science Board, National Science Foundation, 2022). Studies have also shown that international students and faculty experience similar issues of discrimination and exclusion (e.g., George Mwangi et al., 2016; Laufer and Gorup, 2019) in the academy, despite the fact that they comprise at least one-fifth of the STEM workforce (National Science Board, National Science Foundation, 2022) and are lauded as knowledge producers who bring increased visibility and soft power to the United States, especially in globally competitive STEM fields (Yao and Viggiano, 2019).

Over the last 3 years, the challenges of a global pandemic, widened sociopolitical divides, and heightened racial tensions have increased the sense of urgency around the need to address the pervasive and long-standing unwelcoming culture of STEM higher education. Well-documented increases in mental illness, substance use, and other forms of emotional distress among students in higher education provide further impetus for change (National Academies of Sciences, Engineering, and Medicine, 2021). U.S. higher education has a unique responsibility to ensure that the future generations of scientists and engineers that it educates are simultaneously prepared to solve the world's most vexing problems through discovery and innovation, and positioned to do so amid a rapidly shifting world. At the same time, U.S. higher education must ensure that the STEM ecosystem is equitable and inclusive to address persistent inequities that "shuts out and diverts away too many talented individuals, limiting opportunities for discovery and innovation, and our national potential for the greatest impact" (The White House, 2022). We believe that key to achieving these important goals is creating an undergraduate STEM education culture *and* climate that recognizes and values the humanity of our students.

Motivated by these concerns, the purpose of this article is to argue for a more humanized undergraduate STEM education and to provide a framework to guide efforts toward achieving that vision. We begin by addressing our own positionalities as scholars and as humans, because we recognize that our positionalities frame our approach to this topic. Next, we articulate what we mean by "humanizing STEM education," how humanizing approaches are essential to equity and why this is an imperative right now. At the core of humanizing approaches is recognition of the complexity of individuals and the importance of educating the whole student. To that end, we then offer a guiding framework for conceptualizing the broader ecosystem in which undergraduate STEM students are embedded, and the ways in which all stakeholders in that ecosystem can contribute to the development of a higher education culture that centers students' humanity. We use this framework to outline the ways in which we can move toward meaningful action by articulating reasonable, common sense suggestions for stakeholders in different parts of the ecosystem, including the faculty, student affairs, university leadership, university libraries, professional associations, and external stakeholders. Our aim is to help these stakeholders gain insights on how their individual and collective actions can be harnessed to create a humanized STEM campus ecology. We end with far-reaching recommendations for future directions for research and practice, knowing that humanizing undergraduate STEM education will require continued, indefatigable investment in time, energy, and resources.

Before moving further into this article, we want to make clear how we operationalize the term "minoritized" throughout this manuscript. We ascribe to the use of "minoritized" rather than "minority" as a way to reflect "an understanding of 'minority' status as that which is socially constructed in specific societal contexts" (Stewart, 2013, p. 184). That is, students are minoritized as a result of a process rather than as an assumed identity (Benitez, 2010), and this terminology is a start in moving toward a more humanizing approach to undergraduate students. Thus, in subsequent sections, we refer to minoritized students – which typically would include women, people of color, and international students – as those who are subordinated in status in STEM higher education.

Author positionalities

We recognize the importance of author positionality, which illuminates how we approach the topic of undergraduate STEM education reform. Most importantly, we offer insights on who we are in relation to humanizing STEM education, which is consistent with a relational and humanistic approach in education. We engage in reflexive practices as a way to emphasize "the importance of self-awareness, political/cultural consciousness, and ownership of one's perspective" (Patton, 2002, p. 64). As a result, we are made aware of our positionality, operationalized as "how one is positioned in contrast to those being studied" (Yao and Vital, 2018, p. 194), and describe how we are positioned simultaneously with and against our topic.

The authors began the work that led to this paper through their work on a subcommittee of the National Academies of Science, Engineering, and Medicine's Roundtable on Systemic Change in Undergraduate STEM Education. The subcommittee was assigned the task of exploring ways in which undergraduate STEM education could become more holistic and humanizing. This paper reflects our views as individuals that the system of undergraduate STEM education lacks understanding and appreciation for the conditions within STEM that dishonor the humanity of minoritized students and faculty (Turk-Bicakci and Berger, 2014; McGee, 2020). Collectively, we have nearly a century of accumulated experience in STEM higher education, focusing on examining, building, and offering safe spaces - physical, psychosocial, and emotional - for minoritized students to persist in STEM. We represent the often forgotten front lines of STEM reform that have kept alive the promise of a STEM career for minoritized students and the hope of a diverse STEM workforce for the nation.

While it is a single professional endeavor that has brought us into collaboration with each other, we are both varied and unified in our perspectives on the criticality of prioritizing our own humanity in STEM. On one hand, our individual but similar experiences of – and exasperation with – marginalization, exclusion, aggression, and delegitimization have provided a foundation from which our ideas and interactions can easily flow and flourish into meaningful contributions to the knowledge base. On the other hand, the problem-solving approaches we find useful, and the theoretical and practical frames that guide our thinking, are not as common among us. Additionally, we represent varied social identities, some of which offer us a lens of privilege in understanding STEM higher education and others that come by way of disempowering lived experiences. Individually, we all identify as cis gender; and either as African American woman, Asian American woman, Native American man, or White woman. Our geographical origins span the entire continental United States. Each of us has over 10 years of experience in higher education, as faculty and/or administrator, representing the broadest range of institution types – from Tribal Colleges and Universities and other community colleges and to major research institutions to Historically Black Colleges and Universities.

Many authors have noted the myriad ways in which diversity adds strength to groups (Roberge and Van Dick, 2010; Nielsen et al., 2018). We posit that it is not merely our diversity that is our strength but our capacity to attend to our humanity, and the ways in which our humanity has been shaped by our diverse lived experiences, that gives us strength as a collective. This paper represents that strength and serves as evidence that uniquely different worldviews can exist in a common space, without any of them being disadvantaged, dismissed, reduced, or made to suit an overgeneralized narrative about marginalized groups in STEM. As such, we not only present the best of who we are and the best of what we can do as scholars and educators; we also, hopefully, provide hope for others that humanizing STEM is a real possibility for our lifetime.

What is humanized STEM education?

A fully humanized STEM higher education centers on teaching students, not disciplines, in a way that recognizes and values the complexity and humanity of our students. We argue that first and foremost, this requires an educational environment that honors students for the multiple forms of cultural wealth, including social, linguistic, and familial capital (Yosso, 2005) they bring to their education. Our emphasis on cultural wealth is particularly salient because students from minoritized backgrounds, who possess an "array of cultural knowledge, skills, abilities, and contacts" (Yosso, 2005, p. 69), suffer the greatest negative impacts of the historically racist and gendered cultures and climates within STEM. Humanizing undergraduate STEM education in ways that foreground the lived experiences of all minoritized students is essential for all students and their communities to thrive.

Ultimately, a STEM education culture that embraces students' humanity is one that centers equity and creates a learning environment that supports the mental, emotional, physical, and academic well-being of all students. We argue that well-being is not only a critical factor in students' academic success (National Academies of Sciences, Engineering, and Medicine, 2021) but it is an important outcome of higher education itself (Finley, 2016). In light of the vexing and multiplying challenges discussed at the outset of this article, the immediate and intentional focus on humanizing undergraduate STEM education is a national imperative that can no longer be ignored or left un-operationalized. To that end, we call for postsecondary educators in U.S. higher education, and all those with vested interests in the viability of the nation's global competitiveness in science and engineering, to enact systemic- and individual-behavior-level changes to advance a humanizing approach to undergraduate STEM education, specifically one that puts student overall well-being at the center of the STEM academic enterprise. Such an approach requires a keen awareness of and appreciation for our roles in teaching students, not just disciplines; honors students' humanity, ideologies, and ways of knowing; and gives students experiences that nurture and promote human well-being and flourishing alongside knowledge acquisition and skill development.

Theoretical framework

Our guiding framework for humanizing undergraduate STEM culture is inspired by an ecological model of human development that is grounded in the psychological and educational research literature (Bioecological Systems Theory; Bronfenbrenner and Ceci, 1994; Bronfenbrenner and Morris, 2006). We use this framework to envision the ecology of undergraduate STEM education. In it, students are centered as the primary focus, and other system levels represent multiple aspects of undergraduate STEM teaching and learning (e.g., faculty, advisors, associations, etc.). This guiding framework enables us to conceptualize and articulate the roles that all stakeholders in the educational ecosystem can play in promoting undergraduate STEM student learning, persistence, and well-being.

Figure 1 provides an illustration of our application of this model to an example undergraduate STEM student's ecosystem; however, it is not meant to be a complete depiction of the entire ecosystem. The framework views the student in interaction with a set of nested environments or ecological systems – from micro to macro levels. Students live, work, and learn within multiple specific environments, or "microsystems," including but not limited to academics, co-curriculars, student life/student affairs, family, and work settings. The student is viewed as an active agent in the ecosystem, with development being shaped by reciprocal interactions between the person and their contexts. Importantly, students' interactions with these immediate contexts do not happen in isolation of one another. Rather, the relationships between students' microsystems, also known as the "mesosystem," have implications for individual student development. Students may have congruent, separate, or conflicting experiences in different microsystem settings; strong and supportive links between microsystems lead to optimal outcomes (Bronfenbrenner and Morris, 2006), whereas disconnected or conflicting microsystem contexts may lead to dehumanizing experiences.

Students' immediate environments also interact with and are influenced by "exosystems," or broader institutional structures that do not directly impact the student (e.g., faculty reward systems) yet still affect the student's interactions with their immediate contexts (e.g., by influencing faculty teaching practice). All of these system levels are embedded within a "macrosystem" of cultural beliefs, practices, and value systems and a particular historical time period (part of the "chronosystem") that affect the conditions and processes that exist within the microsystem. These broader system levels can help us identify institution and discipline stakeholders who are removed from the daily life of students yet still have a critical role to play in humanizing the STEM learning environment. A major implication of the model is that a humanized STEM ecosystem is more likely when all members of the academic community see it as their responsibility to contribute and, at a minimum, work in awareness of each others' roles, or at best, engage in coordinated or collective action.

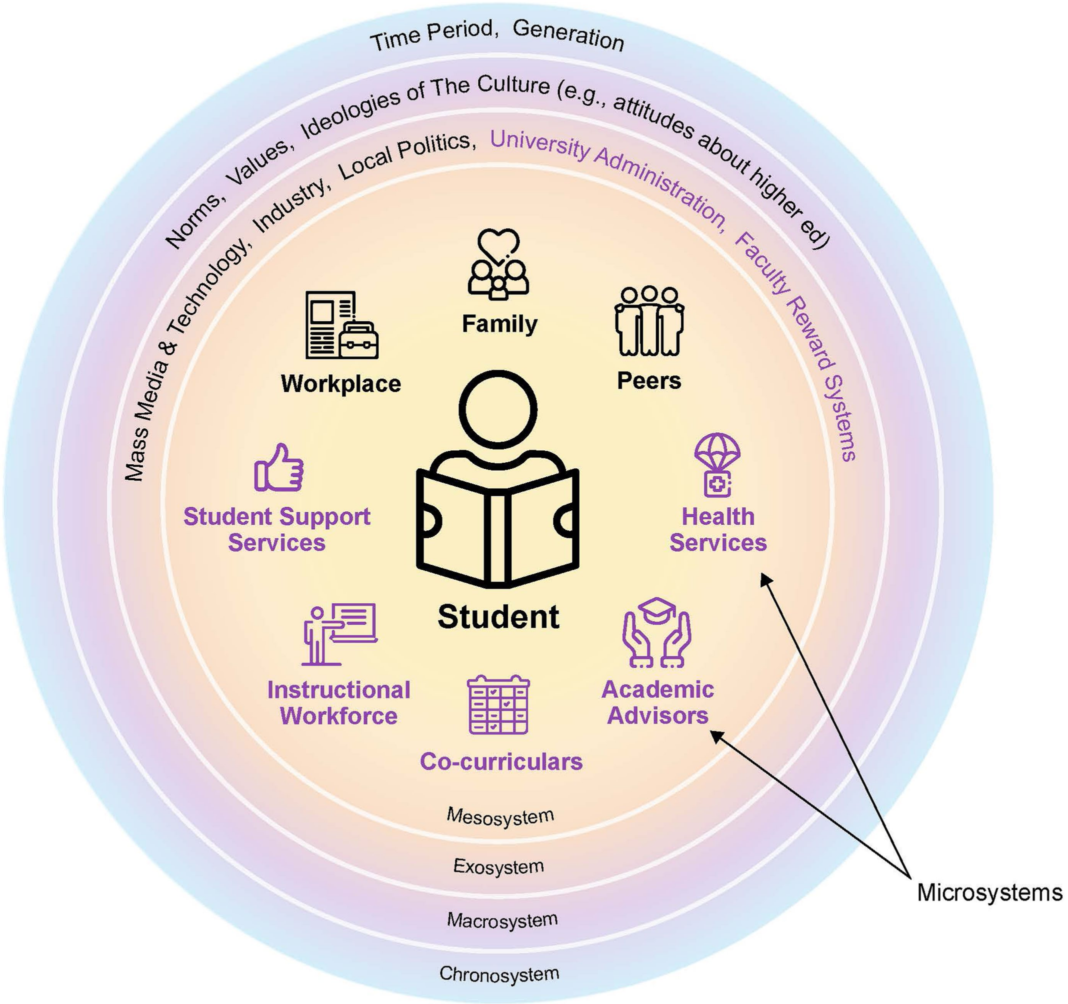

FIGURE 1
A framework to guide humanizing efforts: bioecological systems theory. Items in purple are those that relate to the higher education industry *per se*, representing the stakeholders with responsibility to humanize STEM education.

How can we humanize undergraduate STEM education? Considerations for practice

This application of the Bronfenbrenner model provides a useful frame for comprehensively describing the ways in which students' interactions with their immediate and more distal contexts in the undergraduate STEM ecosystem can serve to humanize (or dehumanize) their educational experiences. We argue that all members of the academic community must see it as their responsibility to work to create, to the best of their abilities, an equitable and empathy-based environment that values the cultural wealth of all students and places student well-being at the center of the academic enterprise. This goal will require work within specific environments, as well as intentional efforts to bridge across commonly siloed settings, to increase awareness and support collective action.

In considering the applications of the ecological model to practice, we focus on the role of stakeholders that, arguably, have the greatest impact on STEM student outcomes: student affairs and student services, academic advisors, faculty, university administration, university libraries, national associations, and external stakeholders/champions. In the sections that follow, we offer a set of recommendations as a first step toward modeling what can be achieved if practices are proposed while simultaneously recognizing, appreciating, and honoring the humanity of our colleagues and counterparts – their intuitions, attitudes, cultural beliefs, and disciplinary expertise. To that end, the reader is only encouraged to ponder, critique, and evaluate these suggestions for feasibility and perhaps potential for adaptability. We caution against assuming the practices noted below are appropriate for all institutional contexts and human capacities; we recognize that higher education institutions are all organized and governed differently and neither can be fully captured or considered in a single article such as this. Thus, we encourage all readers to consider the recommendations below within their own institutional contexts.

Students

Students are at the heart of the imperative to humanize undergraduate STEM education, and the ecological model positions them as active participants in the STEM ecosystem. A considerable amount of research, moreover, has explored the way in which students can take responsibility for navigating their undergraduate STEM careers (e.g., Goodlad, 1998; Colvin and Ashman, 2010; Yao et al., 2021). Despite the demonstrated role of student agency, we argue that it is the responsibility of institutional and discipline stakeholders, not students, to humanize STEM education. Indeed, an emphasis on changing institutions and systems rather than changing students is a central tenet of anti-deficit based approaches to inclusive and equitable education (e.g., García and Guerra, 2004; Peck, 2021). Therefore, in considering the applications of the ecological model for human development (Bronfenbrenner and Ceci, 1994; Bronfenbrenner and Morris, 2006) to the student level, we focus on the role of other stakeholders in amplifying the impact of student voices within the STEM education ecosystem and empowering students toward greater agency and self-actualization in STEM education.

Student affairs and student services

Student affairs and student services support the academic and personal development of students and generally center on student experiences outside of the classroom or in a co-curricular environment (e.g., residential life, student health and mental health centers, multicultural centers, writing centers). As such, these stakeholders are ideally positioned to provide broad and multifaceted support for varying dimensions of student well-being and development, yet this context is often overlooked when it comes to improving students' STEM education experiences. Given that student affairs and student services work is characterized by community building, collaboration, and inclusivity (Espinosa and Nellum, 2015), these administrators may be ideally suited to assist in the success of underrepresented STEM students, whose identities are not reflected in a critical mass on their campus and/or in the classroom. Student affairs professionals are often academically trained in student development theory and are well positioned to contribute to humanized education through student programming that promotes well-being and embraces difference and culturally responsive approaches to relationship building.

Student affairs and student services administrators could also consider ways to engage with stakeholders in other microsystems. For instance, how might they connect their work to the undergraduate STEM curriculum to facilitate learning and development outside the classroom? How might they foster faculty interactions with STEM students in spaces beyond classrooms and labs, such as living learning communities? How can they engage minoritized STEM students who could benefit the most from connecting to a community that allows them to feel supported while allowing them to be their authentic selves (Starr et al., 2022)? For example, Purdue University created the Women in Science Programs (WISP) learning community that has a goal of "offering support by addressing issues of isolation in the STEM field" (Purdue University, 2023). As a result, the program seeks to increase persistence in STEM by offering a variety of programs, including tutoring and mentoring for participants.

Academic advising

Academic advisors often exist in a liminal space between student affairs and academic affairs at an institution. Yet academic advisors are critical to student support because advisors guide students in educational and career pathways throughout students' collegiate career. Thus, it is imperative for academic advisors to consider how to approach their advising of STEM undergraduates in humanizing and culturally sustaining ways. How can academic advisors move toward advising models that honor the humanity of undergraduate STEM students?

One approach is to adopt assets-based advising to create congruent and supportive connections between students' educational pathways and their experiences in other microsystem contexts (e.g., family, work, STEM classroom). Assets-based advising includes actively naming and supporting the needs of racially and gender-minoritized students in STEM (Suárez and Beatty, 2022). From an asset-based perspective, advisors should avoid the advising traditions of linear progress and assumptions of students' backgrounds which historically have molded students into a STEM template that has historically marginalized racially and gender-minoritized students. Rather, advisors must consider how they can understand and account for the complexities of students' lives, including their cultural contexts, multiple knowledges, and mental and emotional well-being. We recognize that not all academic advisors are familiar with assets-based advising, so we recommend that institutions encourage their advising staff to participant in NACADA: The Global Community in Academic Advising learning opportunities, including online resources related to strengths-based advising and learning communities focused on STEM advising (NACADA, 2023).

Faculty

Adjunct professors, teaching professors, tenure track professors, deans, and department chairs can also be called upon to adopt practices that more firmly put students at the center of what they do (Killpack and Melon, 2017). Some faculty actions may be carried out individually, and others collaboratively across an academic program. For instance, like academic advisors, faculty can increase their awareness of and create congruent connections with students' experiences in other settings, such as: becoming familiar with student support systems on campus and advocating for student utilization and adopting teaching practices that center care and empathy (Estrada et al., 2018). They can also design their courses to meet the needs of students with diverse experiences and identities, such as those with full time jobs, illness or mental health issues, or familial responsibilities For example, using in-class time, rather than out-of-class time for group work, or grouping students with similar schedules, can ensure that group participation is accessible to all students. In addition, building structured flexibility into courses, such as the ability to choose between assignments, options to make-up or revise assignments, or specifications or mastery-based grading schemes, can make it easier for students to balance non-academic responsibilities with course responsibilities and learning (White et al., 2021; White and Sangster, 2022).

Other potential faculty actions include centering on how and what they teach. For instance, adoption of active and collaborative pedagogies, which have been repeatedly demonstrated to support better and more equitable student learning (e.g., Theobald et al., 2020), may serve to create an educational environment that is more welcoming of minoritized students, many of whom come from communities that value cooperation and collectivism more than individualism (e.g., Brown, 2008). Faculty can also create learning experiences that center students' humanity by offering opportunities for students to find a sense of purpose in their learning or promoting their personal and ethical development; these sorts of experiences have proven to be particularly important for promoting a sense of belonging among minoritized students (National Academies of Sciences, Engineering, and Medicine, 2018), in part because they place greater value on collective and community priorities (Brown, 2008; White et al., 2021). Example approaches include case- or problem-based learning, inquiry learning, community-engaged learning, or authentic assignments (e.g., Wiggins, 1998; Goeden et al., 2015; Rodenbusch et al., 2016) and infusing themes such as ethics, well-being, and identity into the curriculum (e.g., see the Being Human in STEM initiative developed at Amherst College; Bunnell et al., 2023). Ultimately, faculty must consider—how can they responsibly create inclusive learning environments that can contribute to broadening participation in STEM fields?

University leadership/administration

Arguably, university administrators are the most essential stakeholder responsible for creating an institutional culture in which the humanizing of undergraduate STEM education can occur. Although it is well-established that top-down mandates from university leaders are generally insufficient for broad change (Henderson et al., 2011), university administrators, particularly those at high levels in higher education institutions, do often determine institutional priorities and set the campus tone for excellence and inclusion through communication, modeling and resource allocation. The role of communication was perhaps most evident immediately following the murder of George Floyd and the onset of the COVID-19 pandemic when our academic leaders made numerous policy and position statements expressing concern for the state of our democracy and the wellbeing of all individuals on their campuses.

Language, however, is not sufficient for building institutional capacity for a humanized undergraduate STEM culture. Additional moves could include modeling, as in Howard University President Frederick's (2022) announcement of a Mental Health Day for the entire campus, bringing recognition to others' efforts toward humanizing STEM education, and investing resources in actions and infrastructure that can help all institutional stakeholders in contributing to a humanized STEM. Moving forward, leaders could consider: what institutional conditions will encourage and support other stakeholders in honoring the humanity of our students? How can we bring visibility to this work? How can we elevate student voices and support their agency?

University libraries

University libraries are a key stakeholder in providing a welcoming environment for all students, and creating open and equitable access to library resources and spaces. Over the last decade, university libraries have reduced barriers to entry by extending their services and resources beyond the halls of the physical building by offering digital scholarship services and research methods workshops, making primary sources and research materials available through digitization, and curating datasets and digital collections. Librarians also work with faculty to identify and use open and accessible educational resources (OAER) and create digital repositories to reduce the cost of books and other class materials. By providing alternate access to materials and services, librarians support a broader range of scholarship and learning that fosters equitable access to all students, and specifically minoritized populations (e.g., Hardin et al., 2019).

University libraries can also contribute to a more humanized educational environment by actively diversifying the library's collections and amplifying the voices of minoritized scholars so that libraries play a role in sustaining the cultural wealth of minoritized communities rather than eliminating it (Paris and Alim, 2017; Moreno and Jackson, 2020). In addition to purchasing and showcasing resources published by scholars with minoritized identities, libraries can help faculty to diversify and decolonize the curriculum and curate library guides for diversity in STEM (Morales et al., 2014; Coalition for Diversity and Inclusion in Scholarly Communications, n.d.). University libraries can also collaborate across campus with other microsystems to support undergraduate STEM education. For example, the University of Illinois Chicago Undergraduate Experience Program develops strategic partnerships between the libraries and other units in the student's ecosystem to holistically support student success (Moreno and Jackson, 2020). In one such partnership, a collaboration between the Libraries and the Writing Center addressed the observation that first-year writing students were struggling with evidence gathering by embedding research consultations early in the writing process (Moreno and Jackson, 2020). Libraries, moreover, may also work to humanize STEM students' ecosystem by recognizing and leveraging the ways in which they straddle the academic and social spaces, or microsystems, of students (Moreno and Jackson, 2020). For instance, the Undergraduate Experience Program creates a "Wall of Encouragement" during finals period to provide a public venue for students to encourage each other and express themselves during a stressful period. Moving forward, librarians might ask, how can libraries build programs and partnerships to support STEM education, particularly in both the physical and virtual spaces?

Disciplinary societies and associations

Disciplinary societies and associations play a key role in shaping the systems that undergraduate STEM students navigate because they shape the behaviors, expectations, and norms of STEM cultures (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2005). However, in many ways, disciplinary societies and associations, as racialized organizations (Ray, 2019), contribute to the same centuries-old traditions, conventions, practices, and beliefs that have historically disproportionately advantaged some while marginalizing others in STEM. Therefore, while the national reports and convenings are necessary, it is questioned whether or not they are sufficient for bringing about true and lasting change. Thus, disciplinary societies and associations should consider, how can associations design and deploy far more audacious reform agendas aimed at empowering and emboldening stakeholders of undergraduate STEM education? Indeed, the "non-humanized" stakeholder is powerless in seeing, advocating for, or acting in pursuit of the humanity of undergraduate STEM students.

As an example, the American Association of Colleges and Universities (AAC&U) emerges as a national exemplar in shifting stakeholders, namely faculty and university administrators, from relying too heavily on over-prescribed "tools" to knowing and trusting themselves as undergraduate STEM reformers; and from over-generalizing their lived experiences to building their capacity to critically question, examine, and understand the uniqueness of their institutional contexts. AAC&U's TIDES Institute (Mack et al., 2019; American Association of Colleges and Universities, 2023b) and Project Kaleidoscope STEM Leadership Institute (American Association of Colleges and Universities, 2023a) are designed to shape faculty and administrators through reflection and professional development around leadership for change. In another example, the American Physical Society and the American Association of Physics Teachers have collaborated to develop a comprehensive guide, Effective Practices for Physics Programs (EP3), to promote unit-level reflection and student-centered systemic improvement, These examples illustrate how disciplinary societies and associations can become advocates for humanized undergraduate STEM education and also provide scaffolding for change in stakeholders at other levels of the ecosystem.

External stakeholders/public advocates and champions

External stakeholders and public advocates include entities such as the U.S. government, science centers and museums, science laboratories, non-profit organizations, and the business industry. These entities, which sit at the exosystem level, are unlikely to have a direct influence on undergraduate STEM students but can contribute to efforts humanize their education by bringing attention, dialogue, and resources to the imperative and the work regionally and nationally. These stakeholders can create the conditions to support a more equitable and empathy-based STEM culture, influencing the experiences students encounter in their more immediate contexts, through the provision of visible models, external legitimacy, policy and process development, resource allocation, and collaboration. For instance, the National Academies of Sciences, Engineering, and Medicine Roundtable on Systemic Change in Undergraduate STEM Education that has brought this group of authors together represents an effort to generate interest and foster dialogue among academic scientists and educators, policy makers, federal officials and the business community about the need for STEM education reform and how to achieve that goal (e.g., National Academies of Sciences, Engineering, and Medicine, 2020). Stakeholders in the STEM workforce could also contribute by intentionally shifting their mindset to recognizing and embracing cultural wealth among prospective and current employees through hiring, recognition, and advancement practices. Nonetheless, like disciplinary societies, many of these entities were themselves shaped by a STEM culture and practices that served to dehumanize and marginalize. As a result, external stakeholders might begin by asking themselves, what are our contributions to the current STEM culture? What would a shift look like and how could it bring about much needed change? How can our visibility and collaborations with other stakeholders in the STEM education ecosystem be leveraged to advance change?

Recommendations and future directions

We recognize that every higher education institution is unique, especially when considering institutional type, campus climate, and resource allocation. As a result, we understand that we cannot provide step-by-step instructions on specific tasks to move toward a humanized undergraduate STEM education. To this end, we take the bold position of resisting conventional approaches that propose recommendations for reforming undergraduate STEM education, which far too often treat the reformer like a "machine" that must employ tools or protocols to achieve specific tasks. Sadly, this approach lacks any regard for the lived experience of the reformer and the extent to which the wisdom of that lived experience can yield a better outcome for undergraduate STEM students. Here, we aim to model for the reader a humanized undergraduate STEM education that honors the reader's humanity and their capacity to translate both the practical considerations noted above and the recommendations proposed here into actions and interventions that are reasonable and appropriate given the conditions in which the reader is expected to implement them.

In previous sections, we provided suggestions for stakeholders in undergraduate STEM education as a way to open the conversation for humanizing undergraduate STEM education. In addition, we recognize that silos exist in higher education institutions; however, we argue that it is critical to find ways to bridge these silos in order to effectively humanize STEM education. For example, STEM faculty could also consider partnering with stakeholders in other microsystems to connect programming related to their courses to support students in addressing barriers to success, such as time management (student success units) or information literacy (libraries), or to other domains of personal development, such as the arts (e.g., art museums, performing arts centers) or career aspirations (e.g., career centers, industry partners).

Ultimately, it is imperative for all stakeholders to increase *awareness* of their roles as well as others' responsibilities in STEM education. In demonstrating a deeper understanding of each higher education sector's roles, responsibilities, and resources, stakeholders could then move toward *collective action* and *strategic planning* to consider how to humanize undergraduate STEM education. For example, curriculum design often falls under the purview of faculty, yet power collaborations that also include co-curricular learning could be done by engaging with student affairs, such as through STEM-focused student organizations or living-learning communities. Another example includes embedding education about mental health and wellbeing in all aspects of students' lives, which requires some collaborative training for administrators, faculty, advisors, and student affairs staff.

Humanizing undergraduate STEM education requires investment from each individual, committed to doing the difficult work of transforming education. In considering how to move toward a humanized undergraduate STEM education, we encourage all stakeholders to start with asking reflective questions of themselves, their collaborators, and institutions:

- What makes this work meaningful to you?
- What are you willing to sacrifice for this?

- How are you willing to be an advocate for your students, especially minoritized STEM students?
- How are you willing to advocate for institutional and systemic change?
- How will you resist the status quo?

Ultimately, the responsibility for designing and demanding a humanized undergraduate STEM education lies with us, not our students. We must put student well-being, not content mastery, at the center of the STEM academic enterprise. When we humanize undergraduate STEM education, we focus on teaching students, not disciplines; and we embrace what they bring to their education (e.g., cultural wealth) rather than emphasize their deficits. In doing so, we give all students, particularly minoritized students, an opportunity to gain scientific knowledge and skill alongside – not at the expense of – well-being and human flourishing.

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

CY, AFG, KM, CM, JP, LP, and LY contributed to conception and design of the manuscript and drafted specific sections of the manuscript. CY and AFG revised, connected, and expanded the text. All authors read earlier versions of the manuscript and contributed to revision.

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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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