Biomedical Engineering Education (2023) 3:331–344
https://doi.org/10.1007/s43683-023-00116-4

BMES BIOMEDICAL ENGINEERING SOCIETY

INNOVATION ARTICLE

Approaches to Address New ABET Diversity, Equity, and Inclusion Criteria in Biomedical Engineering Curricula

Sonia Bansal[1] · Aaron M. Kyle[2] · Andrew O. Brightman[3] · Jennifer R. Amos[4]

Received: 7 February 2023 / Accepted: 31 May 2023 / Published online: 15 June 2023
© The Author(s) 2023

Abstract

The lack of diversity in engineering is a persistent problem with few signs of pending improvement. Efforts to promote diversity in engineering schools have produced modest gains. Based on a commitment to be a change leader and fueled by recent updates in ABET criteria to include diversity, equity, inclusion, and justice (DEI-J) as tenets of engineering education, the biomedical engineering (BME) community needs to find new ways to address the issues of DEI for all groups in our curricula. In an attempt to redesign engineering departments to be more inclusive of all student populations, institutions of higher learning are reviewing programs, policies, and the ways they engage students. This paper provides BME programs with some thinking about the integration of DEI into areas of curriculum, assessment, faculty practice and faculty support, infrastructure, and climate for change. This study reports on curricular innovations attempted to date in order to serve as a resource for biomedical undergraduate engineering curricula. The authors have collected critical resources and literature related to integrating DEI into courses and content as well as assessment and evaluation approaches. Sections include resources for BME design, diverse anatomy and physiology, person-centered language, ethics, and assessment and evaluation approaches to measuring climate, faculty, and student impacts. In addition to providing resources, we propose that the ABET DEI framework is missing a critical component: justice. We feel that justice should be emphasized, particularly in biomedical engineering programs because our field has the unique opportunity to promote awareness of injustices and racial disparities in the design, development, and delivery of healthcare and medical technologies. While this paper presents examples of integration in several course types and across different topics, it is intended to inspire additional efforts by the BME community to make more concerted changes to promote DEI in our educational programs.

Sonia Bansal, Aaron M. Kyle, Andrew O. Brightman and Jennifer R. Amos have contributed equally.

✉ Jennifer R. Amos
jamos@illinois.edu

[1] Biomedical Engineering, University of Delaware, Newark, DE, USA

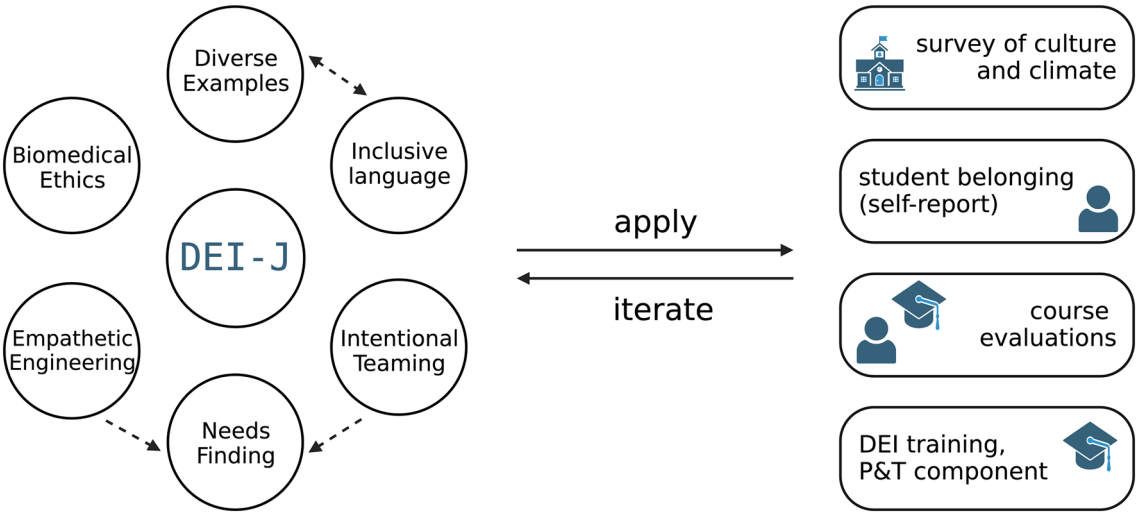
[2] Biomedical Engineering, Duke University, Durham, NC, USA

[3] Biomedical Engineering, Purdue University, West Lafayette, IN, USA

[4] Bioengineering, University of Illinois Urbana-Champaign, Urbana, IL, USA

Graphical abstract

Graphical abstract demonstrating main themes and connections between different themes in the DEI-J framework presented in the paper. Created with BioRender.com.



Keywords Diversity · Equity · Inclusion · Design · Assessment · Curriculum · ABET

Background

National Efforts to Increase Diversity, Equity, and Inclusion in Engineering Curricula

Broadening participation in the engineering workforce is critical to meet the needs of our diverse human population. The workforce must be trained to work in diverse and inclusive contexts where historically oppressed and excluded voices and lived experiences are a valued part of the engineering process. Diversity is now seen as a business necessity driven by the globalization of industry, the desire to have a workforce accepting a wide variety of cultures, and the enhancement of the engineering design process for product development [21, 23, 89]. To this end, diversity research across many disciplines has produced knowledge and practical examples of how to support learning for students from disadvantaged and marginalized communities and produce more inclusive environments for all students [5, 53, 65, 71, 72, 83]. However, there is a barrier to addressing this need, namely the fact that faculty have almost absolute authority and autonomy to guide what happens in their classrooms. Therefore, many believe it is necessary to approach faculty resistance by focusing on a systemic culture shift to a new system of educational norms that drive more effective and widespread inclusivity and equity practices in the classroom. Educational norms such as the reliance on peer and student evaluations as well as the expectation to participate in ongoing training for bias and diversity in the classroom are now commonly required as part of a promotional dossier [1].

To address the need for increased diversity, equity, and inclusion (DEI) in Science, Technology, Engineering, and Mathematics (STEM) education, guidance and programming from the National Science Foundation, the National Institute of Health, and the National Academies have pushed for educational systems to fund programs that aim to train new generations of engineers to address these DEI challenges. While these programs have been successful in increasing inclusive training and programming in participating institutions, the impact is limited to those who choose to participate. Recently ABET, Inc. has joined other agencies in pushing for scale implementation of DEI practices across all engineering programs by including diversity, equity, and inclusion in their accreditation criteria. Any ABET-accredited program will be required to comply with the criteria to maintain accreditation, thereby enabling the culture shift at the institution/systemic level, rather than the individual faculty member level.

ABET, Inc. recently passed changes to two criteria, Criterion 5: Curriculum and Criterion 6: Faculty, to include diversity, equity, and inclusion principles as well as included definitions of diversity, equity, and inclusion into the accreditation definitions. These changes are published by ABET in the criteria for the 2023–2024 accreditation cycle [3] as follows:

Definitions

Diversity is the range of human differences, encompassing the characteristics that make one individual or group different from another. Diversity includes, but is not limited to, the following characteristics: race, ethnicity, culture, gender identity and expression, age, national origin, religious beliefs, work sector, physical ability, sexual orientation, socioeconomic status, education, marital status, language, physical appearance, and cognitive differences.

Inclusion is the intentional, proactive, and continuing efforts and practices in which all members respect, support, and value others.

Equity is the fair treatment, access, opportunity, and advancement for all people, achieved by an intentional focus on their disparate needs, conditions, and abilities.

It is noteworthy that the ABET criteria revisions do not refer to Justice, which is achieving or striving to achieve ongoing fairness while considering the impact of past injustices. While not specifically included, we suggest that Justice also should be contemplated for integration within our engineering curricula. As biomedical innovators, our field has the unique opportunity to reflect on injustices visited upon marginalized communities in the context of racially linked health disparities [51] and biased development and application of medical technologies [37, 76]. As educators, we have the opportunity to teach practices to ensure that these mistakes are not repeated and to create solutions to redress persistent problems. Once exposed to the systems of injustice within which they will work, biomedical engineers will have more appreciation of how their career choices can either perpetuate such systems or break them down [17, 67]. Accordingly, we elect to consider Justice in this article in conjunction with diversity, equity, and inclusion (DEI-J.)

Criteria 5 and 6, with new DEI-specific content, are highlighted below with the new ABET added content italicized and the removed content indicated as both italicized and underlined [3].

Criterion 5: Curriculum

The curriculum requirements specify subject areas appropriate to engineering but do not prescribe specific courses. The program curriculum must provide adequate content for each area, consistent with the student outcomes and program educational objectives, to ensure that students are prepared to enter the practice of engineering.

The curriculum must include:

(a) A minimum of 30 semester credit hours (or equivalent) of a combination of college-level mathematics and basic sciences with experimental experience appropriate to the program.

(b) A minimum of 45 semester credit hours (or equivalent) of engineering topics appropriate to the program, consisting of engineering and computer sciences and engineering design and utilizing modern engineering tools.

(c) A broad education component that complements the technical content of the curriculum and is consistent with the program's educational objectives.

(d) *Content that ensures awareness of diversity, equity, and inclusion for professional practice consistent with the institution's mission.*

(e) A culminating major design experience that (1) incorporates appropriate engineering standards and multiple constraints, and (2) is based on the knowledge and skills acquired in earlier coursework.

Criterion 6: Faculty

The program must demonstrate that the faculty members are of sufficient numbers and they have the competencies to cover all of the curricular areas of the program. There must be sufficient faculty to accommodate adequate levels of student–faculty interaction, student advising, and counseling, university service activities, professional development, and interactions with industrial and professional practitioners, as well as employers of students.

The program faculty must have appropriate qualifications and must have and demonstrate sufficient authority to ensure the proper guidance of the program and to develop and implement processes for the evaluation, assessment, and continuing improvement of the program.

The program faculty must demonstrate awareness and abilities appropriate to providing an equitable and inclusive environment for its students, and knowledge of appropriate institutional policies on diversity, equity, and inclusion. The overall competence of the faculty may be judged by such factors as education, *diversity of* background, engineering experience, teaching effectiveness and experience, ability to communicate, enthusiasm for developing more effective programs, level of scholarship, participation in professional societies, and licensure as Professional Engineers.

Current State of Diversity, Equity, and Inclusion Integration in Engineering Curricula

The curriculum is a central piece of the training puzzle educating a workforce ready to meet the needs of a global marketplace. Isolated attempts have been made to revise the engineering curriculum itself to promote diversity, reinforcing the idea that engineering is focused on technical problem-solving for the benefit of humankind [21].

The new ABET criteria changes would require programs to include content that ensures awareness of DEI-J for professional practice as an engineer. The new curriculum criterion emphasizes that awareness of DEI-J must be tied to professional practice as an engineer, which will increase discussions and applications integrated into engineering curricula rather than the current reliance on general (non-engineering) education requirements to teach social and cultural context. This integration of socially relevant concepts and applications into technical curricula has been studied extensively and has been shown to increase the attractiveness of a curriculum to underrepresented groups as well as communicate the importance of diversity as an integral part of the engineering profession [21].

There are established best practices for the adoption of DEI-J in engineering curricula. A commonly held approach is that the successful adoption of diversity and inclusion-enhancing programs must begin with clearly defining the problem of underrepresentation using data-driven analysis [83]. Further, they recommend that efforts to promote the adoption of diversity-enhancing classroom interventions should start with faculty training designed to increase awareness that diversity and inclusion are important for student success and professional practice. The inclusion of faculty-related elements into the new DEI-J criteria is aimed at this aspect of implementation. By creating an awareness of policies and practices conducive to implementing curricular changes, programs can hold individual faculty members accountable for including social context and DEI-J content in their technical courses.

Some fields, such as psychology and medicine, already require diversity-related topics to be covered in the curriculum as training for professional practice. In a study of 648 higher-education psychology instructors, researchers asked instructors if they covered diversity-related topics and what methods they used to integrate the topics into the classroom [68]. The researchers found that 88% of faculty members included diversity-related topics in lectures, and 85% used class discussion as a means to instruct students on diversity-related topics [68]. Only 15% of respondents claimed to use active-learning models of teaching for diversity-related topics. Another study looked at the use of syllabi, classroom policies, and classroom-management approaches as a place for the integration of diversity-related concepts [85]. The study also asked faculty to identify barriers to implementing diversity-related topics in their courses. Perceived barriers were time constraints or balancing technical content with diversity-related content (57%), lack of training or access to resources for diversity-related content (36%), or a perceived lack of fit concerning other content that needed to be covered (21%) [85]. When asked what would help them address the barriers, 48% of instructors responded that they wanted workshops or training on how to incorporate into their specific content or courses and 32% wanted someone they could turn to for guidance on incorporation or teaching the content [85].

This paper aims to provide guidance on how DEI-J can be incorporated into BME curricula with the forthcoming ABET Criteria 5 and 6 updates in mind. We focus on three areas for curricular integration (design, anatomy & physiology, and ethics) as well as on assessment and evaluation of DEI-J efforts.

DEI-sign

Per Criterion 5-d(e), all students who graduate from an ABET-accredited program must have a "culminating major engineering design experience that (1) incorporates appropriate engineering standards and multiple constraints and (2) is based on the knowledge and skills acquired in earlier course work" [3]. As our field progresses toward more intentional and frequent integration of DEI-J into our engineering practice, this knowledge will be regularly imparted throughout students' undergraduate educations. More specifically, DEI-J is (or should be) an organic part of the engineering design process, from how we uncover and select problems to the resultant devices we design and testing that demonstrates the efficacy and safety of solutions. With just a bit of deliberation, one can reasonably see how DEI-J issues can be readily integrated into the design and development of new technologies. Additionally, by integrating DEI-J into design education, programs might synergistically address the design criterion with the new diversity, equity, and inclusion elements in the curriculum criterion (5-d).

As BME educators in ABET-accredited programs, many design instructors employ some form of the Biodesign process codified and popularized by Paul Yock and colleagues at Stanford University [92]. Through this iterative process, schematically displayed in Fig. 1, innovators are able to uncover problems (IDENTIFY), generate solutions (INVENT), and devise strategies to translate findings to the real world (IMPLEMENT). We propose how DEI-J matters can and should be considered when devising biomedical solutions and provide initial guidance on how DEI-J-sign can be taught, and ultimately assessed, in preparation for the eminent DEI-J considerations in Criterion 5.

Identify Identifying and evaluating needs present clear, but often neglected, opportunities to bring DEI-J into design activities. Because needs finding and screening are foundational to design efforts, bringing diversity considerations into play from the start makes these issues more integral to the subsequent steps of the design process. Diversity and inclusion in the needs stage can be emphasized by ensuring that a variety of backgrounds and interests are considered when deciding what sorts of needs will be pursued. These

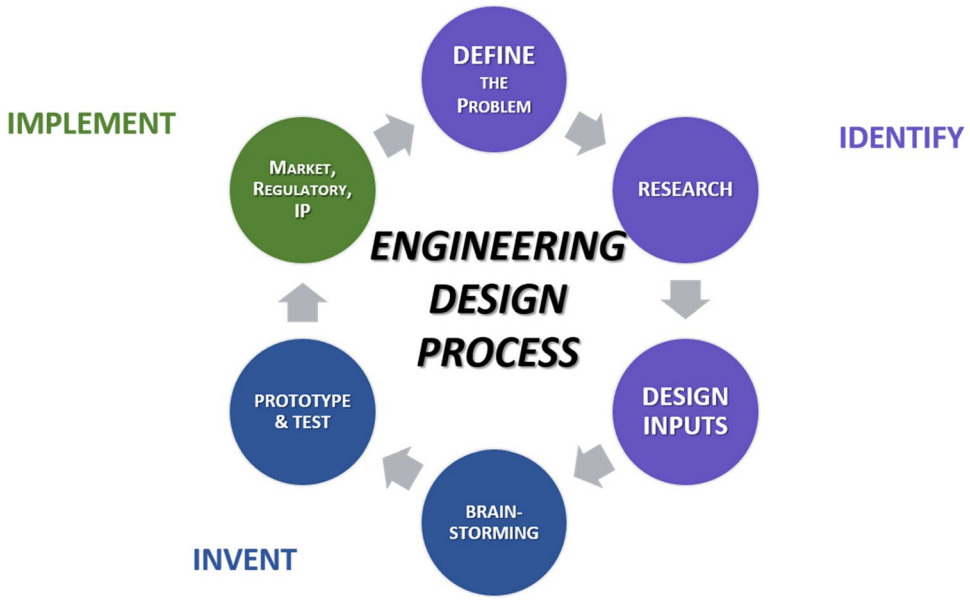


Fig. 1 Visual representation of the Biodesign process as defined by Yock et al. [6].

considerations extend to both the design team members' backgrounds as well as the persons who might drive or benefit from a solution. This goes beyond simply pondering diversity; the experiences and perspectives (particularly of underserved and historically excluded groups), should be welcomed, respected, and embraced. Issues may arise when teams are homogenous, but diversity considerations with design teams present an opportunity to emphasize empathy within the design process. That is, by bringing in diversity considerations, students and instructors should examine issues from perspectives beyond their own for the sake of enhancing their understanding of a design problem. For example, given that engineering remains a male-dominated field, one could foresee challenges with an all- or majority-male team working on a women's health challenge like an early detection system for mastitis during breastfeeding. While a group of undergraduate male designers might not know about this issue due to youth and experience, this sort of problem presents a unique opportunity for such a team. The members of a team would have to learn about the underlying disease state fundamentals of this problem but would also have to extend themselves to develop an understanding of the needs of women. Students would have to empathize to cultivate a nuanced understanding of the problem beyond pathophysiology and solution deficits. Encouraging a multi-perspective approach promotes diversity consideration and will lead to more well-rounded, insightful engineers.

Striving for equity in needs finding emphasizes that designers can define and evaluate needs free from prejudicial views. Objective analysis and elucidation of needs are critical as this may overcome some of the discomforts that often accompany addressing (what might be) sensitive social issues, e.g., high maternal mortality rates for Black women [55] or how social issues like redlining have affected the health outcomes in impoverished communities [52]. By focusing on validated facts, the needs of underserved groups can be explicitly defined and addressed. Finally, justice can be achieved in design efforts by focusing on problems and groups traditionally underserved. That is, by taking on challenges related to groups whose needs have been marginalized or neglected, designers have the unique opportunity to rectify healthcare disparities.

Identifying problems and needs that are informed by DEI-J considerations can be challenging. Historically, the needs of the underserved have not been considered, but there is more information about the biomedical challenges for these communities. For example, a PubMed search of keyword terms "pulse oximetry" and "skin color" performed on April 7, 2023, yields 111 results with 61 of these publications from the past 10 years. While only one specific example, this sort of finding indicates that there is increasing attention to an issue like potential racial disparities in pulse oximetry. The increasing focus on healthcare shortcomings for the underserved can provide some initial direction for innovators embarking on these sorts of design efforts.

A process for incorporating DEI-J concerns into the identification phase of Biodesign largely depends on the iterative development of a need. Design is inherently iterative, but by repeatedly revising needs, including more specificity with each pass, designers can clarify the issue that they are trying to address. We propose that at least a portion of need revision should include examining if there are opportunities to address the needs of diverse groups or to promote equitable healthcare outcomes for those that are underserved.

If we consider a project need statement, framed using the structure from [92], we define a need in terms of a problem

that affects a specific population to achieve a desired outcome (Fig. 2a). Utilizing this generalized structure, we find opportunities to bring DEI-J into a need statement. We can identify an underserved population whose needs might not have been addressed in previous solutions to the problem. By re-framing the population aspect for a specific group or underserved community, we can bring diversity and inclusion into the need (Fig. 2b). Similarly, by addressing the need for a specific community, we can strive for equity and justice in the need, which can be framed in the outcome. The goal for the design efforts becomes about both addressing biomedical deficits while serving groups whose needs have not been previously met. As an example, a generic need statement and its DEI-J iterated counterpart might appear as:

Need	We need a way to detect and track moles for people in their home to improve early monitoring of pre-cancerous skin lesions.
DEI Iterated	We need a way to detect and track moles for darker-skinned people whose moles appear in hard-to-see locations, i.e., soles of the feet, scalp, fingernail beds, to improve early detection and treatment of pre-cancerous lesions, which have been shown to be first detected at later, more dangerous points for darker-skinned persons.

By specifying that mole detection is for darker-skinned persons, we focus the problem on the needs of underserved groups, i.e., racial minorities or people with skin tones that are not considered in dermatological training sets. It has been shown that the difficulty in early detection of lesions in darker-skinned people results in their advancing to potentially deadly cancers, resulting in poorer healthcare outcomes for these people compared to their fair skinned counterparts [92]. This is a clear equity and justice issue that would be missed with the more generic version of the need statement. While both versions of the need are sufficient, we see how readily a DEI-J lens can be applied to a conventional problem, adding specificity to the need. The DEI-J iterated version of the need also provides an opportunity for innovation focused on developing a solution for an underserved group, potentially supporting similar healthcare outcomes as the broader populace.

Invent DEI-J considerations can similarly inform the development and testing of solutions, especially when invention efforts stem from intentional DEI-J needs. Creating ideas during brainstorming presents opportunities for innovation teams to encourage and appreciate ideas contributed from different perspectives (diversity and inclusion). Also, because effective brainstorming is inherently judgment-free, the process promotes equity among team members. Solution screening and selection embrace inclusivity by driving innovators to apply design inputs (guidance) from underserved stakeholders. Transitioning from a pool of ideas to testable prototypes demands welcoming and including inputs from diverse teams to create and refine devices. All of these activities can and should be done under the umbrella of achieving justice by creating devices for underserved groups.

The invention phase of Biodesign presents an opportunity to intentionally apply DEI-J in the selection of a prospective solution. Brainstorming encourages the creative generation of a large pool of ideas that may address a need. We generally strive to avoid over-constraining the idea generation process, hence one might be hesitant to account for DEI-J at this phase. Instead, we suggest first developing a varied set of ideas. DEI-J considerations can be used in the process of selecting which prospective solutions to pursue, i.e., screening and scoring ideas. For example, the pool of ideas can be screened with respect to whether a solution would best serve a broad population or an underserved group that is the focus of a DEI-J iterated need statement. We can use DEI-J considerations to initially screen the pool, taking a set of viable ideas to smaller subset, all of which could address the needs

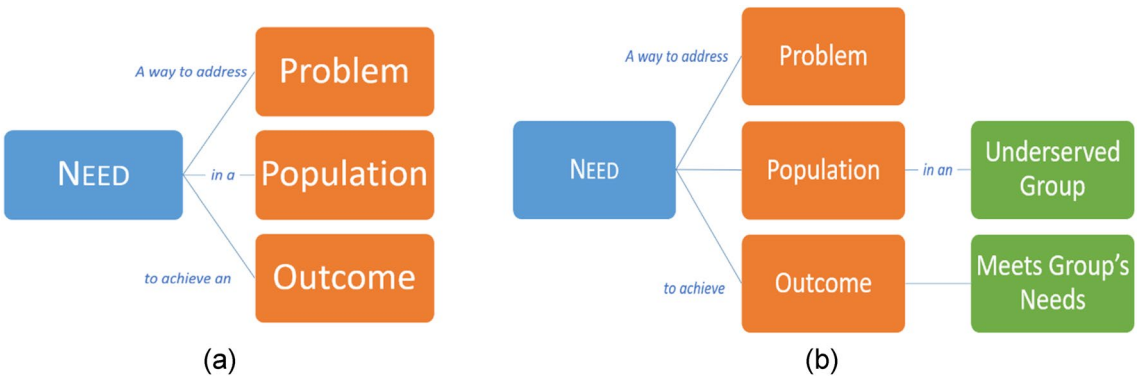


Fig. 2 **a** Convention formulation of need statement from Biodesign process. **b** Structure of need statement augmented by DEI-J-based iteration

with diversity in mind. DEI-J could also be used in an idea scoring activity. For example, when using a decision matrix to select an approach, a scoring criterion could be related to whether a solution would address the needs of an underserved group. The criterion could be weighted to ascribe the appropriate emphasis with regards to addressing the need.

Let us consider, a design team developing a device to automate a capillary refill time test. Capillary refill time is a qualitative diagnostic that doctors use to determine blood flow and to detect shock. It largely relies on pressing a tissue bed until it blanches and monitoring for restored flushing of the tissue bed. In developing ideas for this problem, a team might consider methods including a red color sensor to determine when the skin flushes after pressing. While this is a viable idea, it probably would not pass a DEI-J screen because it might not be appropriate for darker-skinned users. This would also present and opportunity for expanding an idea set. With the DEI-J consideration, another version of colorimetry could rely on examining when the tissue returns to its previous color, not just reddening. Figure 3 provides a visual of an example of how DEI-J can enhance ideation.

DEI-J also factors into prototype development and evaluation. DEI-J should come into play from proof of principle stages all the way through clinical trials. While we cannot account for the specific needs of every prospective device user, it is critical that we attempt to account for variability in users, especially in developing devices for underserved. Without contemplating these needs early and throughout development and testing, we can be easily misled into concluding that a solution will address the needs of different communities. An excellent example of prototyping and testing with diversity in mind comes from the Precise Advanced Technologies and Health Systems for Underserved Populations (PATHS-UP) Engineering Research Center (ERC). One of the focus areas of this collective is the creation diagnostic devices for underserved groups. For diagnostic devices using optical techniques like pulse oximeters and transdermal glucose sensors, the group is rightly investigating how skin tone, obesity, or other characteristics of the target communities might affect the development and performance of their technologies [14, 34, 70]. By considering the needs of their target communities throughout device R&D, groups like PATHS-UP demonstrate the importance of DEI-J in biomedical device design.

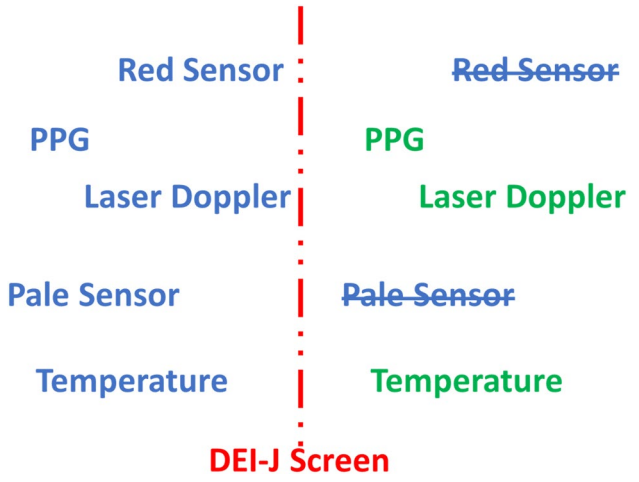


Fig. 3 Example of DEI-J considerations in idea screening, DEI-J screen applied to idea pool for automated capillary refill time monitor. Ideals that are not appropriate for a variety of skin tones do not pass the screen.

Implement We use Implementation to generally refer to the activities that occur beyond the creation of a biomedical solution, including but not limited to obtaining IP, regulatory approval, and business strategy. Clinical testing and obtaining regulatory approval are particularly important phases for DEI-J considerations in MedTech development. The FDA specifically promotes creating diverse populations in drug trials to ensure that sample groups are representative of the broader population [87]. It is reasonable to assume that similar guidance is, or should be, applicable to medical devices. Getting underrepresented groups to participate in clinical trials requires substantial cultural considerations of equity and justice. The mistrust that groups may feel about medical testing due to previous injustices requires consideration and respect to fully diversify study groups. For example, we can consider COVID-19 vaccine hesitancy among Black people. Despite Black Americans being among the groups worst impacted early in the pandemic, with mortality rates 2.5 times that of the general population, their reticence about getting the vaccine was comparable to White counterparts [51]. While a host of factors give rise to resistance to adopting this life-saving biotechnology, as biomedical innovators, we may consider factors such as: (1) the historic medical injustices related to medical innovation, e.g., the Tuskegee Syphilis study, and (2) issues with testing vaccines in underserved communities. With justice in mind during testing and regulatory approval, issues associated with hesitancy could be pre-emptively addressed.

It is widely recognized that, despite representing increasing proportions of the population, disparities persist in the number of women and underrepresented minority (URM) patent holders [37, 46]. These deficits redound to the types of disparities in (medical) technologies that may not appropriately serve broader communities. Inventorship and intellectual property (IP) represent the type of meritocracy that quality DEI-J efforts should strive to achieve. That is, because inventorship cannot be attributed without an explicit definition of contribution to an invention, increasing the number of women and URMs that hold patents is a reflection of successful diversification. We assert that increasing the pool of inventors requires diverse groups where inclusion is emphasized, allowing traditionally underrepresented

members to develop their contributions to the point where they can attain IP.

Business planning and market analysis for underserved communities present particularly interesting challenges. Because DEI-J efforts often pertain to underrepresented groups, the sheer number of persons who might benefit from these solutions can be low, making it difficult to establish that these needs are financially viable, resulting in DEI-J considerations being considered altruistic endeavors. For example, even though children's healthcare is an important need space, the number of afflicted children is often so low, not provide sufficient incentive to pursue these needs. The challenge for the innovator will be in ascribing some value to achieving justice and providing equitable access to solutions.

A table that summarizes possible DEI-J integration into each design phase is included in the supplemental materials (Online Resource 1).

Incorporating Diverse Examples Throughout Undergraduate Courses

Another possible avenue for incorporation of DEI-J in Biomedical Engineering Curricula involves the continual recognition of how racial, gender, socioeconomic, and geographic diversity of experience informs anatomy, physiology, disease, and disability. These topics are relevant in design classes, as has been discussed already in this paper, but they have also been successfully incorporated into core engineering and elective courses [43, 74, 81, 88]. For example, the mention of the hidden bias in pulse oximetry due to patient skin color during a core course (mass and fluid transport) creates an opportunity for discussion [46]. Not only does it relate to coursework directly as an example of blood oxygenation and saturation, but it also highlights the importance of diversity-conscious clinical care and reminds students that current clinical decision-making was structured around devices built for homogenous populations. This creates an opportunity for reflection and ties into the importance of inclusive design in other courses. Similar conversations can occur in biomechanics classes around the anatomical differences between those who are assigned male or assigned female at birth. Perhaps the most well-known examples are the biases against female and pregnant persons when verifying vehicle safety [15, 16, 66]. The inclusion of such examples in a technical class provides an opportunity to solve the biomechanical effect of sex or pregnancy while also highlighting the need to think inclusively when approaching biomedical engineering problems. Another example includes a thorough investigation of machine learning and artificial intelligence training data for bias in imaging studies. Whether for dermatologic [40] or endocrine [50] diagnoses, a "bias in, bias out" framework is important to discuss in bioinformatics or imaging classes. These conversations can prompt students to think critically about the models they choose to develop and use throughout their careers in professional practice. Collaboration with faculty members in public health, sociology, policy, and other departments can yield not only more diverse classroom discussions but also introduce our students to the diversity of thought more generally. Similarly, focusing on low-resource settings in bioinstrumentation courses or health disparities in device design courses can infuse multi-year curricular elements with issues of justice, equity, inclusion, and diversity. Through these curricular integrations, we continue to acknowledge the impacts that diversity plays not only in the lived experience of others but also in creating more equity-minded and inclusive engineers.

Inclusive Language

The use of inclusive, "person-centered" language can be a subtle but important way to consider the diversity associated with disability and to enhance equity and inclusivity in the engineering classroom. It is a framework in which the individual is referred to before their disability, thus acknowledging that any person is not primarily defined by their disability. This, in conjunction with the use of common, respectful terms such as "wheelchair user" instead of outdated terms such as "handicapped" or "wheelchair-bound" [2] is an important and deliberate choice to center and respect the population that is being referred to within curricula. Indeed, several studies have found that stigmatizing language is found broadly in academic and clinical publications [7, 41, 42, 63, 84], which highlights the importance of using person-centered language early and often to build an understanding of its importance. Awareness of the appropriate terminology is also particularly relevant when considering design or clinically oriented courses in which students may be working with actual persons with physical, cognitive, or emotional disabilities. By emphasizing person-centered language, we are training students to speak to community partners, clients, sponsors, and clinicians more appropriately and are enhancing their professional development.

Awareness of DEI-J Through Ethics

Ethics education can be a logical place in a BME curriculum to bring awareness to issues of DEI-J [73]. Ethics is understood as the intentional consideration of what is the right thing to do that is supported by attention to principles, values, and purpose in a specific context. As most BME programs are already integrating ethics education into their curricula, addressing DEI-J issues in this context can be both

efficient and effective. Although the application and teaching of the four principles of biomedical ethics (*non-maleficence*, *beneficence*, *respect for autonomy*, and *justice*) have varied widely in BME, their relevance to the field can be easily seen [8]. Linking these principles to DEI-J provides an opportunity to help students develop a practical understanding of these four principles by providing real-world context [9, 20]. For example, biomedical engineers cannot completely evaluate the safety (non-maleficence) and effectiveness (beneficence) of novel medical technologies without considering DEI-J given that FDA guidance for the med-tech industry includes standardizing the approaches for collecting and reporting diversity data concerning medical device testing. As with clinical trials, the FDA expects med-tech developers to enroll participants who reflect the demographics for clinically relevant populations with regards to age, gender race, and ethnicity" and devise plans for inclusion of relevant subpopulations [27, 33, 36]. This FDA guidance can be used as a teaching resource for creating awareness of DEI-J issues by students preparing for professional practice. Similarly, biomedical engineers cannot ethically practice respect for autonomy and justice without considering DEI-J issues. An effective ethics case study for biomedical engineering that deals with issues of choice, equitable distribution, and global access is Merryman's 'Development of a tissue-engineered heart valve for pediatrics" [58].

Teaching ethics in coordination with DEI-J also contributes to the professional preparatory aspects of engineering education. Companies increasingly recognize that well-managed diversity, equity, and inclusivity efforts are important for better outcomes in organizational productivity [24, 45], resilience [12, 30], and economic success [11, 62, 64]. Many companies now make attempts to address DEI-J issues in a variety of ways, including via their codes of ethics. An organizational culture that values and supports diversity, equity, and inclusion contributes to better ethical outcomes for a company [44, 57]. These findings can be important aspects to include in courses on professionalization for biomedical engineers as they prepare for careers in high-stress companies developing medical technologies in an intensely competitive and regulated market.

Assessment and Evaluation of DEI-J Efforts

An important first step in assessing and evaluating programming in DEI-J is to do a pre-assessment. For faculty, it is important to understand the awareness and perceptions of faculty before starting new programming. Gay states that "the first principle of practice is that personal and professional belief about diversity based on race, ethnicity, language, culture, social class, and nationality shape instructional beliefs" [38]. Another pre-assessment that can be done is to curate a collection of course artifacts such as course syllabi, schedules of topics, quizzes, exams, or other assessments. In these collections of materials, a program can keep a count of courses that include DEI-J concepts, what topics are covered, what topics are assessed, and evidence of inclusive teaching practices. Examples of inclusive teaching practices may be seen in a syllabus such as courses that include Universal Design for Learning (UDL) principles and multiple modes of representation for enhanced accessibility of teaching materials or courses that include a diversity statement [54].

Climate and Culture of Department Assessments

While a change in individual faculty member behavior and courses is certainly beneficial, enduring change is systemic, where the impacts go beyond the classroom to policies, practices, and culture [29]. This makes the department level the ideal unit for DEI-J integration into education. Similar to the continuous improvement practices where faculty measure and reflect on achievements in student learning outcomes, measuring, and tracking the department climate leads to meaningful change. An example of this process in practice can be seen through a project formed by the National Science Foundation (NSF), the National Institute of General Medical Science of the National Institutes of Health, and the Howard Hughes Medical Institute called the Partnership for Undergraduate Life Sciences Education (PULSE) [19, 29]. The PULSE Program was designed to provide undergraduate life science departments with a framework for assessment and guided self-reflection in climate for change including assessment rubrics to assess curriculum, assessment practices, faculty practices, support, infrastructure, and climate for change [19]. PULSE added new rubrics specifically focused on DEI-J in 2022 to address a gap in the tools available to departments to measure DEI-J efforts [18]. The DEI-J Rubrics focus on many of the same areas with attention to DEI-J. For instance, the curriculum rubric focuses on the integration of high-impact practices and inclusive pedagogy as well as the inclusion of racially diverse perspectives and bias in curricular topics. The faculty rubric includes measures for faculty awareness of terminology, availability of faculty professional development related to DEI-J, and opportunities for faculty to engage in anti-racism work. The climate for change rubric focuses on recruiting and retaining faculty, addressing bias in policies, and ensuring equity across marginalized identities [18]. Additionally, the PULSE program encourages formative annual assessment and self-reflection every year with a summative assessment every 5 years—a cycle that aligns nicely with the 6-year ABET cycle. While not exhaustive, the PULSE DEI-J rubric will help departments begin to properly assess the current state of their DEI-J efforts and help support departmental growth.

The PULSE system can be used along with many of the methods described below for student and faculty assessments for a comprehensive frequent, ongoing assessment of the program.

Student Assessments

To assess the student experience in a program, there are many ways that one can assess the environment related to DEI-J. Following are some assessments that can be used to assess the student experience and monitor changes over time as changes are made to the curriculum and faculty training.

Belonging is described as a student's perceived social support on campus, a feeling or sensation of connectedness, the experience of mattering or feeling cared about, accepted, respected, valued by, and important to the group (course, program, campus, or community) or others in the context on campus (e.g., faculty, peers) [77, 82]. Belonging and inclusion are synonymous in terms of identifying perceived cultural norms and identification with a field [77]. An important tenet of the sense of belonging and inclusion is that they are context-dependent [60]. In other words, individuals can experience a sense of belonging to various contexts simultaneously, and levels of belonging in these various contexts can have an impact on each other, much like the intersectionality of identities [77]. Additionally, a sense of belonging to specific contexts (e.g., a classroom, major, or graduate program) is positively associated with academic persistence [91]. Many have shown that short belonging surveys for specific and surrounding contexts can be monitored over time in a program in engineering, even in less formal settings like workshops and conferences [47, 77, 91].

Another measure that partners with belonging is psychological safety. Psychological safety is often measured in team environments to assess a shared belief that the team is a safe space for interpersonal risk-taking [32]. Further, psychological safety has been shown to facilitate learning behavior in team or class environments because it alleviates concern about others' reactions to actions that have the potential for embarrassment or threat, which learning behaviors often have [10]. Edmonson's 7-item questionnaire is often used for this purpose, to understand the risk-taking behavior of each student, team, or class as a whole. The survey presents positive and negative team statements such as, "If I make a mistake in the team, it is held against me, "It is safe to take risks in this team," and "Working with members of this team, my unique skills and talents are valued and utilized" and asks patients to respond on a scale of strongly disagree to strongly agree. Another similar concept is to measure whether a learning environment is a respectful environment. This can be measured using social presence and can be integrated into early informal feedback to check in with students for different types of learning activities and varied learning spaces, including online learning [69].

Faculty Assessments

A modified version of Andersen's [6] affective learning scale has been shown effective at measuring participants' attitudes about diversity and their perceptions of preparedness for dealing effectively with diverse learners in the classroom [75]. Similar to Bloom's Taxonomy [49] learning scale, Andersen's learning scale measures the progression in the depth of a skill using descriptions of behaviors and actions that can be measured in practice through observation or measured by a survey to capture student perceptions [75]. The affective scale moves from receiving, a willingness to pay attention, to responding, reacting voluntarily or complying, to higher level skills like organization, rearrangement of value system, to characterization by value, incorporation of value into life [75]. The survey asks questions about their attitude toward diversity training their attitude about the behaviors recommended in my program, their likelihood of attempting to engage in the behaviors, etc. [75]. The survey instrument used to assess Andersen's scale was shown to be effective at comparing pre/post-results to evaluate training or programmatic changes.

Another way to evaluate training effectiveness is to assess faculty integration of the training and concepts into and outside of classroom activities. There has been a push to formalize recognition of faculty for work in DEI-J for some time. In 2016, there was a movement in higher education calling for requirements in the tenure promotion process for valuing DEI-J-related work [1]. Many schools followed suit and instituted formalized processes, including Pomona College, Rutgers University, and the University of Illinois Urbana Champaign [35, 80]. The University of Illinois has included DEI-J requirements into annual review criteria and tenure promotion requirements for all faculty [60]. These criteria are publicly available as well as the guides for how DEI-J will be used in promotion cases [25, 39].

Classroom Assessments

Another method of evaluating the effectiveness of teaching interventions is using teaching evaluations. Many large institutions have begun to include DEI-J-related items related to inclusive behavior and diversity topic coverage in their standard teaching evaluations [49]. There are many examples in literature, but one example related to biomedical engineering is from Crandall in the MedEd Portal [26]. This paper outlines diversity topic coverage in a 1st- and 2nd-year medical curriculum. The activities and materials evaluated spanned case examples, problem sets, class discussions, etc. some with minor changes, such as changing the race

or ethnicity of the patient discussed, using ethnic names for patients or in examples in class, and discussion of diseases and disorders that disproportionately affect certain cultures in the curriculum, similar to the authors recommend in this paper. Crandall includes in the resources for this paper the examples used in the courses as well as grading rubrics for DEI-J items, learning contracts, as well as course evaluation items used to assess the effectiveness of the coverage [26].

Discussion

This paper describes several ways in which biomedical curricula can integrate and emphasize diversity, equity, and inclusion to create student awareness and aid in professional preparation for future careers and professional practice. Herein are examples of integration in varying course types and across many different topics, the paper is the beginning of efforts that will continue to grow in the coming years as programs make more concerted efforts to promote DEI in biomedical curricula.

While this paper focuses on curriculum and assessment changes that BME curricula can use to enhance coverage of DEI-J topics, there is also a need for broad change in infrastructure and systems that support BME departments. This has been called to the forefront in many recent publications citing the need for attention and research to address gaps in gender inequity of health care solutions and lack of support for female scientists as well as lack of funding for black scientists [48, 59, 90].

As mentioned previously, the focus of these changes is not limited to academic environments, the impact is on educating the future workforce to revolutionize professional practice as well. As such, there has been an increase in the implementation of training and culture shifts in the engineering practice [12, 45, 86]. The professional code of ethics, as authored by the Biomedical Engineering Society also seeks to educate and promote ethics across the community [13]. In 2021, the code of ethics was updated specifically to include language around diversity, respect, and professional behavior standards [13].

By taking a multipronged approach to the integration of DEI-J in BME Programs, the trajectory of healthcare innovations can be revitalized by a new generation of BME workforce who are prepared to implement strategies leading to impactful long-term changes.

Citation Diversity Statement

Recent work in several fields of science has identified a bias in citation practices such that papers from women and other minority scholars are undercited relative to the number of papers in the field [22, 28, 31, 56, 61]. Here, we sought to proactively consider choosing references that reflect the diversity of the field in thought, form of contribution, gender, race, ethnicity, and other factors. First, we obtained the predicted gender of the first and last author of each reference by using databases that store the probability of a first name being carried by a woman [31, 93]. By this measure (and excluding self-citations to the first and last authors of our current paper), our references contain 31% woman(first)/woman(last), 31% man/woman, 19% woman/man, and 19% man/man. This method is limited in that (a) names, pronouns, and social media profiles used to construct the databases may not, in every case, be indicative of gender identity and (b) it cannot account for intersex, non-binary, or transgender people. Second, we obtained predicted racial/ethnic category of the first and last author of each reference by databases that store the probability of a first and last name being carried by an author of color [4, 78, 79]. By this measure (and excluding self-citations), our references contain 2% author of color (first)/author of color(last), 9% white author/author of color, 20% author of color/white author, and 69% white author/white author. This method is limited in that (a) names and Florida voter data used to make the predictions may not be indicative of racial/ethnic identity, and (b) it cannot account for Indigenous and mixed-race authors, or those who may face differential biases due to the ambiguous racialization or ethnicization of their names. We look forward to future work that could help us to better understand how to support equitable practices in science.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s43683-023-00116-4.

Author Contributions SB engaged in numerous discussions with authors, presented on topic at session at BMES, and served as primary author on Recognition of Diverse Anatomy and Physiology and Person-Centered Language sections. AMK engaged in numerous discussions with authors, presented on topic at session at BMES, and served as primary author on DEI-sign section. AOB engaged in numerous discussions with authors, presented on topic at session at BMES, and served as primary author on Ethics as DEI Integration section. JRA gathered group to form concept for paper, engaged in numerous discussions with authors, and presented on topic at session at BMES, and is a primary author for Background, Assessment and Evaluation of DEI Efforts, and Discussion.

Funding None.

Data Availability None.

Code Availability None

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Approval None.

Consent to Participate None.

Consent for Publication None.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

1. Abdul-Raheem J. Faculty diversity and tenure in higher education. J Cult Divers. 2016;23(2):53–6.
2. Accessibility and accommodations: making opportunity accessible to all. Family Voices. 2006. https://familyvoices.org/wp-content/uploads/2019/04/Accessibility-and-Accommodations.pdf. Accessed 15 Oct 2022.
3. Accreditation Criteria & Supporting Documents. ABET, Inc. https://www.abet.org/accreditation/accreditation-criteria/. Accessed 9 Jan 2023.
4. Ambekar A, Ward C, Mohammed J, Male S, Skiena S. Name-ethnicity classification from open sources. In: Proceedings of the 15th ACM SIGKDD international conference on knowledge discovery and data mining. 2009, p. 49–58.
5. Amos JR, Hunter CD, Clancy KBH, Tillman AS. Race, inclusion, and science: things that really do go together. In: 2015 ASEE annual conference & exposition. 2015, p. 26–1299.
6. Andersen JF. Teacher immediacy as a predictor of teaching effectiveness. Ann Int Commun Assoc. 1979;3(1):543–59. https://doi.org/10.1080/23808985.1979.11923782.
7. Arnhart C, Neale M, Collins C, Chesher T, Coffey S, Rogers T, Ottwell R, Hartwell M. The use of person-centered language in scientific research articles focused on autism. J Dev Behav Pediatr. 2022;43(2):63–70. https://doi.org/10.1097/DBP.0000000000001038.
8. Beauchamp TL. The 'four principles' approach to health care ethics. Princ Health Care Ethics. 2007;29:3–10.
9. Beever J, Brightman AO. Reflexive principlism as an effective approach for developing ethical reasoning in engineering. Sci Eng Ethics. 2016;22(1):275–91.
10. Beigpourian B, Luchini F, Ohland MW, Ferguson DM. Psychological safety as an effective measurement in engineering classrooms. In: 2019 ASEE annual conference & exposition. 2019. https://doi.org/10.18260/1-2--33214.
11. Beraki MT, Tessema MT, Dhumal P, Ready KJ, Kelati S. Exploring the correlation between diversity and financial performance: an empirical study. Int J Bus Perform Manag. 2022;23(1/2):206–23.
12. Blatt R. Resilience in entrepreneurial teams: developing the capacity to pull through. Front Entrep Res. 2009;29(11):1.
13. BMES Code of Ethics. 2021. https://assets.noviams.com/novi-file-uploads/bmes/PDFs_and_Documents/Governance/BMES_Code_of_Ethics_2021_-_Revised_October_2021.pdf. Accessed 9 Jan 2023.
14. Boonya-Ananta T, Rodriguez AJ, Du Le VN, Ramella-Roman JC. Monte Carlo analysis of optical heart rate sensors in commercial wearables: the effect of skin tone and obesity on the photoplethysmography (PPG) signal. Biomed Opt Express. 2021;12(12):7445–57.
15. Booth GR, Cripton PA, Siegmund GP. The lack of sex, age, and anthropometric diversity in neck biomechanical data. Front Bioeng Biotechnol. 2021. https://doi.org/10.3389/fbioe.2021.684217.
16. Bose D, Segui-Gomez, ScD M, Crandall JR. Vulnerability of female drivers involved in motor vehicle crashes: an analysis of US population at risk. Am J Public Health. 2011;101(12):2368–73. https://doi.org/10.2105/AJPH.2011.300275.
17. Bothwell MK, McGuire J. Difference, power and discrimination in engineering education. In: Xing J, Li J, Roper L, Shaw S, editors. Teaching for change. Lanham: Lexington Books; 2007.
18. Brancaccio-Taras L, Awong-Taylor J, Linden M, Marley K, Reiness CG, Uzman JA. The PULSE Diversity Equity and Inclusion (DEI) rubric: a tool to help assess departmental DEI efforts. J Microbiol Biol Educ. 2022;29:e00057-e122. https://doi.org/10.1128/jmbe.00057-22.
19. Brancaccio-Taras L, Pape-Lindstrom P, Peteroy-Kelly M, Aguirre K, Awong-Taylor J, Balser T, Cahill MJ, Frey RF, Jack T, Kelrick M, Marley K. The PULSE vision & change rubrics, version 1.0: a valid and equitable tool to measure transformation of life sciences departments at all institution types. CBE Life Sci Educ. 2016;15(4):ar60. https://doi.org/10.1187/cbe.15-12-0260.
20. Brightman AO, Beever J, Hiles MC. Next-generation ethical development of medical devices: considering harms, benefits, fairness, and freedom. In: Next-generation ethics: engineering a better society. 2019. p. 387–410.
21. Busch-Vishniac IJ, Jarosz JP. Can diversity in the undergraduate engineering population be enhanced through curricular change? J Women Minor Sci Eng. 2004;10(3):255–82.
22. Caplar N, Tacchella S, Birrer S. Quantitative evaluation of gender bias in astronomical publications from citation counts. Nat Astron. 2017;1:1–5.
23. Chubin DE, May GS, Babco EL. Diversifying the engineering workforce. J Eng Educ. 2005;94(1):73–86.
24. Cohen-Charash Y, Spector PE. The role of justice in organizations: a meta-analysis. Organ Behav Hum Decis Process. 2001;86(2):278–321.
25. Communication #9: Promotion and tenure—office of the provost [Internet]. [cited 2023 Jan 9]. Available from: https://provost.web.illinois.edu/policies/provosts-communications/communication-9-promotion-and-tenure/.
26. Crandall S. Elective course in culture and diversity. MedEdPORTAL. 2005. https://doi.org/10.15766/mep_2374-8265.192. Accessed 3 Jan 2023.
27. Culp MBB, Lunsford NB. Peer reviewed: melanoma among non-Hispanic black Americans. Prev Chronic Dis. 2019;16:E79.
28. Dion ML, Sumner JL, Mitchell SM. Gendered citation patterns across political science and social science methodology fields. Polit Anal. 2018;26:312–27.
29. Dolan EL. Next steps for vision and change: moving from setting the vision to change. CBE Life Sci Educ. 2012;11(3):201–2. https://doi.org/10.1187/cbe.12-06-0082.
30. Duchek S, Raetze S, Scheuch I. The role of diversity in organizational resilience: a theoretical framework. Bus Res. 2020;13(2):387–423.
31. Dworkin JD, Linn KA, Teich EG, Zurn P, Shinohara RT, Bassett DS. The extent and drivers of gender imbalance in neuroscience reference lists. arXiv Preprint. 2020. https://arxiv.org/abs/2001.01002.
32. Edmondson A. Psychological safety and learning behavior in work teams. Adm Sci Q. 1999;44(2):350–83.

33. FDA 2022—diversity plans to improve enrollment of participants from underrepresented racial and ethnic populations in clinical trials; Draft guidance for industry; Availability draft guidance for industry. 2022.
34. Fine J, Branan KL, Rodriguez AJ, Boonya-Ananta T, Ramella-Roman JC, McShane MJ, Coté GL. Sources of inaccuracy in photoplethysmography for continuous cardiovascular monitoring. Biosensors. 2021;11(4):126.
35. Flaherty C. Where DEI work is faculty work [Internet]. Inside Higher Ed. 2022 [cited 2023 Jan 9]. Available from: https://www.insidehighered.com/news/2022/04/01/u-illinois-require-diversity-statements-tenure.
36. Flores LE, Frontera WR, Andrasik MP, Del Rio C, Mondríguez-González A, Price SA, Krantz EM, Pergam SA, Silver JK. Assessment of the inclusion of racial/ethnic minority, female, and older individuals in vaccine clinical trials. JAMA Netw Open. 2021;4(2):e2037640.
37. For Black Inventors, Road to Owning Patents Paved With Barriers. Bloomberg News. 2020. https://news.bloomberglaw.com/ip-law/for-black-inventors-road-to-owning-patents-paved-with-barriers. Accessed 15 Oct 2022.
38. Gay G. Classroom practices for teaching diversity: an example from Washington State (United States). https://doi.org/10.1787/9789264079731-15-en.
39. Guide to Diversity, Equity, and Inclusion (DEI) Work in the Promotion and Tenure Process. The University of Illinois Urbana-Champaign. 2022. https://provost.illinois.edu/policies/provosts-communications/communication-9-promotion-and-tenure/.
40. Guo LN, Lee MS, Kassamali B, Mita C, Nambudiri VE. Bias in, bias out: underreporting and underrepresentation of diverse skin types in machine learning research for skin cancer detection—a scoping review. J Am Acad Dermatol. 2021. https://doi.org/10.1016/j.jaad.2021.06.884.
41. Hartwell M, Naberhaus B, Arnhart C, Ottwell R, Dunn K, Rogers TC, Vassar M, Beaman J. The use of person-centered language in scientific research articles focusing on alcohol use disorder. Drug Alcohol Depend. 2020;216:108209. https://doi.org/10.1016/j.drugalcdep.2020.108209.
42. Headley S, Potter I, Ottwell R, Rogers T, Vassar M, Hartwell M. Adherence rates of person-centered language in amputation research: a cross-sectional analysis. Disabil Health J. 2022;15(1):101172. https://doi.org/10.1016/j.dhjo.2021.101172.
43. Hendricks DG, Yuliana F. Teaching social justice to engineering students. In: 2021 ASEE virtual annual conference content access. 2021.
44. Hoang T, Suh J, Sabharwal M. Beyond a numbers game? Impact of diversity and inclusion on the perception of organizational justice. Public Adm Rev. 2022;82(3):537–55.
45. Hofhuis J, Van Der Rijt PG, Vlug M. Diversity climate enhances work outcomes through trust and openness in workgroup communication. SpringerPlus. 2016;5(1):1–14.
46. Increasing the diversity of patent recipients: a look at efforts to broaden the participation of underrepresented groups in the patent process offers promise, while at the same time points to other problems in the patent system. State of Women in Engineering220, SWE Magazine. 2020. https://alltogether.swe.org/2020/03/increasing-the-diversity-of-patent-recipients/. Accessed 15 Oct 2022.
47. Jensen KJ, Cross KJ. Engineering stress culture: relationships among mental health, engineering identity, and sense of inclusion. J Eng Educ. 2021;110:371–92. https://doi.org/10.1002/jee.20391].
48. Koning R, Samila S, Ferguson JP. Who do we invent for? Patents by women focus more on women's health, but few women get to invent. Science. 2021;372(6548):1345–8.
49. Krathwohl DR. A revision of Bloom's taxonomy: an overview. Theory Pract. 2002;41(4):212–8. https://doi.org/10.1207/s15430421tip4104_2.
50. Larrazabal AJ, Nieto N, Peterson V, Milone DH, Ferrante E. Gender imbalance in medical imaging datasets produces biased classifiers for computer-aided diagnosis. Proc Natl Acad Sci USA. 2020;117(23):12592–4. https://doi.org/10.1073/pnas0.1919012117.
51. Laurencin CT. Addressing justified vaccine hesitancy in the black community. J Racial Ethn Health Dispar. 2021;8(3):543–6. https://doi.org/10.1007/s40615-021-01025-4.
52. Lee EK, Donley G, Ciesielski TH, Yamoah O, Roche A, Martinez R, Freedman DA. Health outcomes in redlined versus non-redlined neighborhoods: a systematic review and meta-analysis. Soc Sci Med. 2021. https://doi.org/10.1016/j.socscimed.2021.114696.
53. Long L III, Mejia JA. Conversations about diversity: institutional barriers for underrepresented engineering students. J Eng. 2016;105(2):211.
54. Lowrey KA, Hollingshead A, Howery K, Bishop JB. More than one way: stories of UDL and inclusive classrooms. Res Pract Pers Sev Disabil. 2017;42(4):225–42. https://doi.org/10.1177/1540796917711668.
55. MacDorman MF, Thoma M, Declcerq E, Howell EA. Racial and ethnic disparities in maternal mortality in the United States using enhanced vital records, 2016–2017. Am J Public Health. 2021;111(9):1673–81. https://doi.org/10.2105/AJPH.2021.306375.
56. Maliniak D, Powers R, Walter BF. The gender citation gap in international relations. Int Organ. 2013;67:889–922.
57. Mayer DM, Kuenzi M, Greenbaum R, Bardes M, Salvador RB. How low does ethical leadership flow? Test of a trickle-down model. Organ Behav Hum Decis Process. 2009;108(1):1–13.
58. Merryman WD. Development of a tissue engineered heart valve for pediatrics: a case study in bioengineering ethics. Sci Eng Ethics. 2008;14(1):93–101.
59. Mirin AA. Gender disparity in the funding of diseases by the US National Institutes of Health. J Womens Health. 2021;30(7):956–63.
60. Mitchell JD, Simmons CY, Greyerbiehl LA. Intersectionality & higher education. New York: Peter Lang; 2014. https://doi.org/10.3726/b15089.
61. Mitchell SM, Lange S, Brus H. Gendered citation patterns in international relations journals. Int Stud Perspect. 2013;14:485–92.
62. Onyeador IN, Hudson SKT, Lewis NA Jr. Moving beyond implicit bias training: policy insights for increasing organizational diversity. Policy Insights Behav Brain Sci. 2021;8(1):19–26.
63. Ottwell R, Heigle B, Reddy AK, Sajjadi N, Wirtz A, Cook C, Howard H, Hartwell M, Vassar M. The use of person-centered language in medical research journals focusing on psoriasis: cross-sectional analysis. JMIR Dermatol. 2021;4(1):e28415. https://doi.org/10.2196/28415.
64. Paul G, Kovvali S. The other diversity dividend. Harvard Business Review, July–August 2018. https://hbr.org/2018/07/the-other-diversity-dividend. Accessed 6 July 2022.
65. Pawley AL. Learning from small numbers: studying ruling relations that gender and race the structure of US engineering education. J Eng Educ. 2019;108(1):13–31.
66. Pearlman MD, Viano D. Automobile crash simulation with the first pregnant crash test dummy. Am J Obstet Gynecol. 1996;175(4):977–81. https://doi.org/10.1016/s0002-9378(96)80036-6.
67. Polyakova M, Udalova V, Kocks G, Genadek K, Finlay K, Finkelstein AN. Racial disparities in excess all-cause mortality during the early COVID-19 pandemic varied substantially across states: study examines the geographic variation in excess all-cause

mortality by race to better understand the impact of the COVID-19 pandemic. Health Aff. 2021;40(2):307–16.
68. Prieto LR, Whittlesey V, Herbert D, Ocampo C, Schomburg A, So D. Dealing with diversity issues in the classroom: a survey of the STP membership. Teach Psychol. 2009;36(2):77–83. https://doi.org/10.1080/00986280802529236.
69. Prince M, Felder R, Brent R. Active student engagement in online STEM classes: approaches and recommendations. Adv Eng Educ. 2020;8(4):1–25.
70. Rodriguez AJ, Boonya-Ananta MT, Gonzalez M, Le VND, Fine J, Palacios C, McShane MJ, Coté GL, Ramella-Roman JC. Skin optical properties in the obese and their relation to body mass index: a review. J Biomed Opt. 2022;27(3):030902–030902.
71. Ross MS, Huff JL, Godwin A. Resilient engineering identity development critical to prolonged engagement of Black women in engineering. J Eng Educ. 2021;110(1):92–113.
72. Secules S, Gupta A, Elby A, Tanu E. Supporting the narrative agency of a marginalized engineering student. J Eng Educ. 2018;107(2):186–218.
73. Shields B. Justice, equity, diversity, and inclusion curriculum within an introductory bioengineering course. Biomed Eng Educ. 2022. https://doi.org/10.1007/s43683-022-00086-z.
74. Shields B. Justice, equity, diversity, and inclusion curriculum within an introductory bioengineering course. Biomed Eng Educ. 2023;3(1):39–49.
75. Simonds BK, Lippert LR, Hunt SK, Angell ME, Moore MK. Communication and diversity: innovations in teacher education. Commun Teach. 2008;22(2):56–65. https://doi.org/10.1080/17404620802040536.
76. Sjoding MW, Dickson RP, Iwashyna TJ, Gay SE, Valley TS. Racial bias in pulse oximetry measurement. N Engl J Med. 2020;383(25):2477–8. https://doi.org/10.1056/NEJMc2029240.
77. Smith TF, Wilson D, Jones DC, Plett M, Bates RA, Veilleux NM. Investigation of belonging for engineering and science undergraduates by year in school. In: 2012 ASEE annual conference & exposition. 2012. p. 25–858. https://doi.org/10.18260/1-2--21615.
78. Sood G, Laohaprapanon S. Predicting race and ethnicity from the sequence of characters in a name. arXiv Preprint. 2018. https://arxiv.org/abs/1805.02109.
79. Stevens KR, Masters KS, Imoukhuede PI, Haynes KA, Setton LA, Cosgriff-Hernandez E, Eniola-Adefeso O. Fund black scientists. Cell. 2021;184(3):561–5.
80. Stewart M. Colleges revise tenure requirements to include diversity and inclusion accomplishments [Internet]. INSIGHT Into Diversity. 2021 [cited 2023 Jan 9]. Available from: https://www.insightintodiversity.com/colleges-revise-tenure-requirements-to-includediversity-and-inclusion-accomplishments/.
81. Storm K, Zhang J, Haase E. Development and implementation of a health equity-focused Python and machine learning module in an introductory BME course. Biomed Eng Educ. 2022;2(2):167–74.
82. Strayhorn TL. College students' sense of belonging: a key to educational success for all students. London: Routledge; 2018.
83. Thoman DB, Yap MJ, Herrera FA, Smith JL. Diversity interventions in the classroom: from resistance to action. CBE Life Sci Educ. 2021;20(4):ar52.
84. Traxler B, Nicks S, Puckett M, Dunn K, Croff JM, Hartwell M. The use of person-centered language in scientific research articles focusing on opioid use disorder. Drug Alcohol Depend. 2021;228:108965. https://doi.org/10.1016/j.drugalcdep.2021.108965.
85. Uddin MM, Johnson KV. Identifying classroom management strategies by focusing on diversity and inclusion. In: 2018 ASEE annual conference & exposition. 2018. https://doi.org/10.18260/1-2--30593.
86. Unconscious Bias @ Work | Google Ventures. 2014. https://www.youtube.com/watch?v=nLjFTHTgEVU. Accessed 9 Jan 2023.
87. US Food and Drug Administration. Enhancing the diversity of clinical trial populations—eligibility criteria, enrollment practices, and trial designs guidance for industry. 2020. https://www.fda.gov/regulatory-information/search-fda-guidance-documents/enhancing-diversity-clinical-trial-populations-eligibility-criteria-enrollment-practices-and-trial. Accessed 15 Feb 2021.
88. Walsh AJ, Raghavan S. Design and implementation of privilege for sale, a JEDI activity for a biomedical engineering introductory course. Biomed Eng Educ. 2022;2(2):183–8.
89. Watson K, Froyd J. Diversifying the US engineering workforce: a new model. J Eng Educ. 2007;96(1):19–32.
90. White J, Clayton J. The gender health innovation gap: a perspective from the NIH Office of Research on Women's Health. Med. 2022;3(5):298–301.
91. Wilson DM, Bell P, Jones D, Hansen L. A cross-sectional study of belonging in engineering communities. Int J Eng Educ. 2010;26(3):687–98.
92. Yock PG, Zenios S, Makower J, Brinton TJ, Kumar UN, Watkins J, Denend L, Krummel TM, Kurihara CQ. Biodesign. Cambridge: Cambridge University Press; 2015.
93. Zhou D, Cornblath E, Stiso J, Teich E, Dworkin J, Blevins A, Bassett D. Gender diversity statement and code notebook, v1.0. 2020. https://doi.org/10.5281/zenodo.3672110.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.