Designing for Diversity, Equity, and Inclusion in Systems Engineering Education

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Abstract

Technology is often thought to be unbiased; however, the views, perspectives, and experiences of designers are embedded in technology. These biases, whether conscious or unconscious, have resulted in technologies that have been particularly harmful for marginalized populations. One way to mitigate these biases is to incorporate diversity, equity, and inclusion (DEI) principles into engineering education, specifically within the domain of systems engineering and related fields that focus on designing systems for humans. This paper focuses on exploring the experiences of professionals in systems engineering and related fields that have integrated DEI into their work to provide recommendations for how DEI principles can be integrated into engineering education. Participants were recruited online and through snowball sampling. Semi-structured interviews were completed with 15 participants either over the phone or on a video chat platform. These interviews were analyzed through inductive content analysis, which yielded three themes related to integrating DEI into systems engineering education: curriculum development, course design, and educator development. The results from this study align with recent calls in higher education to decolonize the curriculum. Beyond strategies like ensuring representation in class readings and changing course requirements, this study adds the need to educate students in methods like participatory design that aim to reduce power dynamics and incorporate diverse perspectives throughout the design process.

Introduction

Assumptions and biases are embedded into design, whether intentionally or unintentionally, and have had disparate effects on marginalized communities. For example, facial recognition technology is less likely to recognize people of color [1], attempts to automate public benefit systems have resulted in exacerbating adverse outcomes among low-income individuals [2], and seat belt design based on the average male body puts female drivers at a higher risk for injury [3]. The designs of these solutions are typically reliant on the designers mental model [4] and do not account for the social, economic, physical, and cultural factors [5] salient within the user's mental model. The 'designers' and thus their mental models are typically similar, as there is a lack of diversity in STEM fields [6].

The damage these exclusionary solutions have caused cannot be undone. However, as engineers, especially in systems engineering, we can examine how diversity, equity, and inclusion (DEI) principles can be integrated throughout the design process, from needs assessments to prototypes through dissemination and iteration to prevent further differential impact of engineering designs. Most importantly, educators can integrate these principles into engineering curricula to develop students that are conscious of how to design tools and technologies with DEI principles in mind as they go on to their careers. These principles include designing with a wide range of users, especially those who have been historically marginalized, and ensuring that these designs are not exacerbating inequities and continuing to privilege the same populations [7].

Though increasing diversity in the engineering workforce could contribute to mitigating bias in design [8] and there are many efforts to improve recruitment and retention of diverse students [9], progress can also be made to how students are educated about systems engineering practice. This includes not only incorporating more diverse perspectives and voices in course content but also questioning the historical foundations of methodologies and standards [10]. Therefore, the purpose of this study was to investigate current perspectives and methods being used to account for DEI in the design process and how these are and could be incorporated into systems engineering education. This paper specifically focuses on the latter and provides recommendations from professionals in systems engineering and closely related fields on how they have and would like to integrate DEI principles into systems engineering education.

Methods

Sample
To be eligible for the study, participants had to be over the age of 18, have experience with DEI and systems engineering or closely related fields (e.g., human factors psychology, human-computer interaction, or computer science), and have at least an undergraduate degree in a systems engineering or a closely related field.

Recruitment
Participants were identified via online searches using terms such as "DEI and engineering," "DEI and design process," and "DEI and technology design" to find individuals through platforms such as professional websites, conference agendas, and scholarly publications. Those that met the eligibility criteria were contacted via email with additional information about the study. Recruitment also occurred through postings on professional organization forums. Those interested in the study contacted the research team via email. Lastly, participants were recruited through snowball sampling [11]. Participants received a $50 gift card as compensation for their time.

Data Collection
Data collection occurred from September 2020 to January 2021. Interviews were semi-structured in nature and lasted about an hour. All interviews took place over the phone or on a video chat platform. Participants were read an informed consent script prior to starting the interview. Oral consent was audio recorded and with the permission of the participant, the interviews were audio recorded as well. The interview guide included the following topical sections: relationship between DEI and engineering, how DEI is integrated into the research and design process, and how DEI is and could be integrated into systems engineering education. Participants were asked open-ended demographic questions so they could self-identify and not be forced into categories [12]. Audio recordings were stored on a secure server and deleted from the initial recording device once uploaded.

Data Analysis
All audio recordings were transcribed. Data were analyzed through qualitative content analysis through an inductive process [13]. As the interviews covered topics beyond engineering education, only excerpts related to pedagogical approaches were coded. This process began with gaining an initial impression of the data by reading the first five transcripts and iteratively

drawing themes. These themes made up the preliminary codebook. This codebook was then used to code the remaining transcripts. New themes were added as they emerged. All themes and subthemes were defined in the final codebook.

Ethics Approval
This study was approved by the social and behavioral sciences institutional review board at the University of Virginia.

Results

Sample Characteristics
Fifteen participants completed interviews (Table 1). The average age of participants was 33 years old. A majority of the participants identified as female and as an underrepresented minority in STEM fields. Sixty percent of participants had attained a doctorate degree and 80 percent primarily worked in academic settings. All participants currently worked or had previously worked in the United States (US).

Table 1. Sample demographics (n=15)

	Number (%)
Age	
20-29	4 (27)
30-39	8 (53)
40-49	3 (20)
Gender Identity	
Male/Man	2 (13)
Female/Woman	10 (67)
None	1 (6)
Non-binary	1 (6)
Queer	1 (6)
Underrepresented Minority in STEM Fields	
Yes	10(67)
No	4 (27)
I don't know	1 (6)
Education	
Bachelors	2 (13)
Bachelors and Masters	4 (27)
Bachelors and/or Masters and PhD	9 (60)
Primary Setting	
Academia	12 (80)
Industry	3 (20)

Themes

Three overarching themes were identified through qualitative content analysis (Table 2). All themes touch on ways DEI can be integrated into systems engineering education.

Table 2. Themes identified through qualitative content analysis

Theme	Definition
Curriculum Development	The entirety of experiences that comprises a course of study
Course Design	The structure of specific learning environments for students
Educator Development	The opportunities available to those teaching and/or engaging with students to learn about different perspectives

Curriculum Development

Participants discussed a multitude of ways that current curricula are problematic with regards to DEI. Broadly, the historically exclusive nature of engineering was pinpointed as perpetuating bias and exclusion by multiple participants. For example, one participant noted that standard design principles taught left out certain populations: *"...we leave out 10% of the population in our own curriculum and so I think...the community as a whole is hopefully starting to recognize that those 10% of individuals on either side of the bell curve need to have technology accessible for them as well"* (P3). Another participant called attention to the racist language pervasively used to refer to concepts and structures in their field: *"...when we talk about databases and systems. If you have access you know, it's been called whitelists, if you don't have access, it has been called blacklist and you know that has historical implications as well and we think about power and equity"* (P9). As related to courses, participants mentioned how the content of introductory courses are decontextualized and focus on basic methods rather than incorporate content on potential negative societal consequences. As one participant pointed out, this way of teaching is problematic because: *"...students go through a year to three years of this foundational inherently low context instruction and that's what they start to think engineering is. So the idea that mindset becomes really entrenched. When you finally start getting into applications, the students have already learned this is just math. This is just parentheses. This is just 3D printing. This is just CAD. And because it's been separate from social issues, all that time they don't see the social issues when they do become relevant..."* (P2). Though there are some opportunities for students to engage in specific courses related to DEI topics, a participant made a point that these courses are not typically required and students who enroll in these courses *"know what they are signing up for"* (P12) and are already aware of and interested in learning more about these issues.

One idea raised by many participants was to ensure that all students in a program receive education related to DEI by instituting course requirements in the curriculum. Another idea was to require at least one lecture of a course to be focused on DEI. However, one participant found that idea to be problematic as they thought: *"I don't think that it should just be a thing tacked on at the end. That's like this is social justice day. I think it needs to be integrated with the teaching*

of technical material" (P12). For some participants, integrating DEI into courses and/or requirements was not enough. These participants emphasized the need for DEI to underlie the culture of departments and thus be pervasive throughout the curriculum. For instance, one participant stated: *"Our program pedagogically is very focused on making sure that students have access to critical readings and that they are able to develop a critical consciousness around the way that design interfaces with society like that's like a major component of our program"* (P7). Beyond the environment of an institution of higher education, one participant recognized the need for DEI considerations to be incorporated into internships and experiential learning opportunities available to students: *"I know that's much, much harder to control trying to get a company to make sure they incorporate diversity, equity, and inclusion into their internship experiences or their co-ops. But I think it will be a great way for students to see how what they're learning in the classroom really applies to the real world."* (P6).

Course Design

Specifically related to integrating DEI into the structure of courses, participants discussed at length about several pedagogical approaches. First, a majority of participants talked about incorporating diverse perspectives into readings. Multiple participants included readings from scholars with different identities: *"I ended up really revamping the reading assignments, because like going through the readings that were there. I was like, yes, a lot of these are like quote unquote classics, but there's no reason why you can't read the like you know 20 years newer version of this that was like, written by someone who was not again a cisgender white male"* (P14). Others specifically chose readings focused on DEI topics and/or historically marginalized communities: *"We also used Safiya Noble's Algorithms of Oppression when we were talking about PageRank actually. Safiya Noble has a really lucid explanation of some of the problems with the—and the assumptions that PageRank makes. One of my other favorite texts in this area is Catherine D'Ignazio and Lauren Klein's Data Feminism which I assign as a reading quite often in most of the lectures"* (P8). Another method was to incorporate considerations for marginalized populations into existing course topics. As an example, one participant did not *"fundamentally change what they [courses] were about, but just included accessibility as it made sense...to reinforce this notion that accessibility is a part of what we do"* (P4). Moreover, another participant taught methods and topics that inherently incorporate a range of perspectives: *"[I teach] empathetic design or user centered design...because otherwise engineers tend to design for themselves. And so, exposing students to like the diversity of humans will make them better engineers"* (P1). Prevalent throughout most of the interviews was creating spaces for students to design for minoritized or marginalized populations either through hypothetical exercises or actual engagement. For one class, a participant facilitated opportunities for students to design for individuals with disabilities: *"I've been able to work with nonprofits that were in that space so that my students could actually like work with people who are disabled and then like and actually and do immersive user-centered design with the actual user population..."* (P1). Lastly, a few participants highlighted the importance of incorporating perspectives from other disciplines into the classroom. In one case, a participant incorporated poetry readings into their course: *"[poetry] is a great segue to talk about how humans come in all different shapes and sizes. And if we designed to only fit the stereotypical model of what an attractive human is we're going to exclude a large part of our population and it's really easy to say, you know, if we're excluding people from being able to use products that engineers are building, no one's going to*

buy them or that big part of the population is not going to buy them and your company's going to lose money" (P15).

Educator Development

Participants talked less about how to teach those educating students (e.g. faculty, post-doctoral scholars, and graduate teaching assistants) about DEI issues. One participant did not particularly find formal training beneficial but liked spaces where educators could informally connect: *"We have a luncheon. And there's usually some theme like civility was one theme. And then another theme recently was sort of like seeing racism...we have, like, really great speakers who talk about stuff while you're sitting there munching away on your food, and no one is there taking a class..."* (P2). Another participant organized an informal reading group: *"I mentioned a reading group on equity and justice, and that's been running for the past year, and it welcomes people from across the department. So, staff, faculty, postdocs, undergrad graduate students...it's definitely collective learning and mutual learning"* (P13). Specifically related to courses, participants mentioned collective departmental initiatives to review content of classes and provide more resources related to DEI. In one example, graduate students and post-doctoral scholars conducted *"course audits by looking at syllabi and assignments to ensure that there is representation of scholars of color, women..."* (P13). One participant had the idea to create a departmental resource bank of representative imagery for educators to use in their presentations: *"Another thing that we need to do is make resources available...for updating your slides so that [they] don't just feature white men because that's what you...you Googled scientist and used what comes up"* (P2).

Discussion

Qualitative content analysis yielded three themes related to how to integrate DEI into systems engineering education: curriculum development, course design, and educator development. Across participants, there was an acknowledgment that there are biases within traditional engineering teaching and practices about the design process and that conventional curricula do not typically emphasize DEI topics and perspectives. To address these issues, participants discussed curriculum changes ranging from requiring courses to incorporate DEI topics or creating courses specific to these topics to refocusing cultures of programs to center around DEI principles. Participants also shared specific ways to modify courses from assigning readings from diverse scholars to planning activities that give students the opportunity to design for diverse users to introducing students to methods and materials from other disciplines. To improve the DEI knowledge of educators, participants shared learning experiences including informal training events and reading groups and provided materials and time to colleagues to ensure representation in course readings and presentations.

Even though there have been efforts to improve DEI in engineering education [9], [14], these efforts have mainly focused on student representation and retention. By also developing approaches to educating students about the impacts of DEI on the engineering design process, students would become more aware of the potential impacts, whether positive or negative, of the tools and technologies they will encounter in their careers. The results from this study align with recent calls in higher education to decolonize the curriculum by shifting power dynamics and

changing the status quo of the material that is taught and courses that are required [10], [15], [16]. Efforts to decolonize the curriculum in higher education have mainly focused on the humanities and arts [17]–[19]. Though there have been efforts in fields related to systems engineering, these have mainly been outside of the US [16], [20]; however, conversations have begun in the US but not necessarily with a focus on systems engineering [21]. Similar to the results of this study, one study focused on identifying ways to decolonize engineering education found that curriculum changes are needed and that course material needs to be contextualized [16]. The unique findings from this study add the need to introduce students to methods like participatory design that inherently incorporate DEI by breaking down power dynamics between designers and end-users [22], [23]. By realigning systems engineering education to integrate DEI principles, though more research is needed on how to do this, it is thought that social justice perspectives will become pervasive throughout engineering work [16], [20].

The main limitation of this study is that a majority of participants were recruited online and identified using search terms related to DEI and the engineering design process. This recruitment strategy may have left individuals out who could be experts in this space. However, the participants identified through this avenue had established research and/or strong social media presences surrounding this topic. Another limitation is the low percentage of participants who were professionals in industry. Though since this paper focused on engineering education, it could be beneficial that the majority of perspectives came from those very familiar with and ingrained in the academic space.

Future research would include investigating more perspectives and experiences on this topic through additional interviews. Other qualitative methods like longitudinal journaling could be employed to capture the thoughts and experiences of those integrating DEI principles into systems engineering education. Moreover, students could be included in subsequent studies to capture their perspectives on their education as it relates to DEI. Quantitative methods could also be introduced as another way to assess the effectiveness of any changes in a curriculum.

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