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Designing equitable and inclusive visualizations: An underexplored facet of best practices for research and publishing

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Designing equitable and inclusive visualizations: An underexplored facet of best practices for research and publishing

Equitable and inclusive publishing practices for engineering education research have received increased attention in recent years. *JEE* editorials and guest editorials have raised awareness about multiple challenges, including the problematic Whiteness and maleness of much research and the need to make diversity the default condition (Pawley, 2017), racially biased citation patterns (Holly, 2020), and other general aspects of publishing ethics (Loui, 2016). There are also ongoing discussions in an engineering education journal editors' group about how to increase the inclusivity of our collective publishing practices. For instance, topics such as inclusive pronouns, positionality statements, and how to better involve scholars of color without overburdening them have been discussed. However, inclusive visualization practices have not yet received the same critical attention. Importantly, visualizations can play a number of key roles in manuscripts, such as synthesizing frameworks or literature (Eppler, 2006), showing relationships between core variables (Tufte, 1997), providing illustrative examples of focal phenomena (e.g., see Schimpf et al., 2020), or enabling comparisons of intervention outcomes (Gleicher et al., 2011). Thus, their influence has a wide reach. Just as other aspects of publishing can serve as mechanisms for either exclusion or inclusion, so too can our choices when designing visualizations.

In this guest editorial, we highlight the heretofore unexamined topic of visualization to add to those ongoing efforts to increase the inclusivity of engineering education research publishing practices. The three inclusivity dimensions we discuss are (1) communicating to an interdisciplinary audience, (2) representation equity within visualizations, and (3) readers' physical dis/abilities and differences. In discussing these dimensions and how their associated design decisions can affect the inclusivity of engineering education research, we aim to raise awareness, provide reflective prompts for designing and reviewing visualizations, and ultimately decrease the unintentional use of exclusionary practices. These dimensions are not a definitive list but are intended to encourage a wider discussion within the community about inclusive visualization practices.

Our first dimension of inclusivity involves communicating to an interdisciplinary audience. Engineering education is an interdisciplinary field that brings together scholars from engineering disciplines, education disciplines, and social science fields among others. While some types of complex visualizations (e.g., multivariate box plots or three-dimensional bar graphs) may be standard or common in some of these fields, there are others that very rarely use any visualizations at all. Therefore, not all of the interdisciplinary contributors to engineering education research are equally familiar with all visualization approaches. As such, we need to ensure that visualizations are discernable to the full community so that they do not become inadvertent gatekeepers. For example, to read the boxplot in Figure 1, a reader would need to understand the meaning behind the length of the box, the horizontal line and the glyph within the box, the lines extending below and above the box, the dots beyond the lines, and so forth. If a reader is not familiar with these conventions, he or she is likely to be confused by the figure.

Authors can use several strategies to increase the likelihood that their visualizations will be understood by readers from any discipline. First, visualizations in manuscripts should be accompanied by thorough in-text explanations and descriptive captions of the graphic. These explanations or captions should describe central variables, concepts, or categories depicted and provide guidance on how to read the visualization. Authors should likewise clearly and thoroughly label key components of the graphic (Tufte, 2001). Second, while it may be tempting to display more data by incorporating additional variables, categories, or dimensions into a single graphic to allow visualization-savvy readers to dig deeper, authors should not design overly complex visualizations that incorporate information peripheral to the point(s)

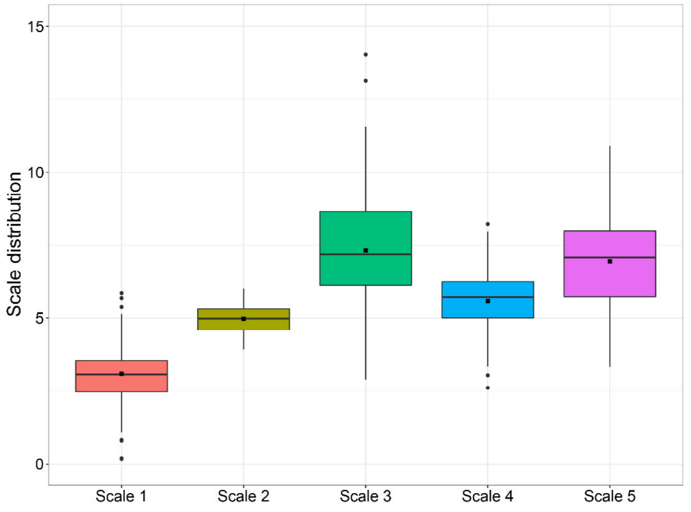

FIGURE 1 A boxplot representing participants' responses on five survey instrument scales [Color figure can be viewed at wileyonlinelibrary.com]

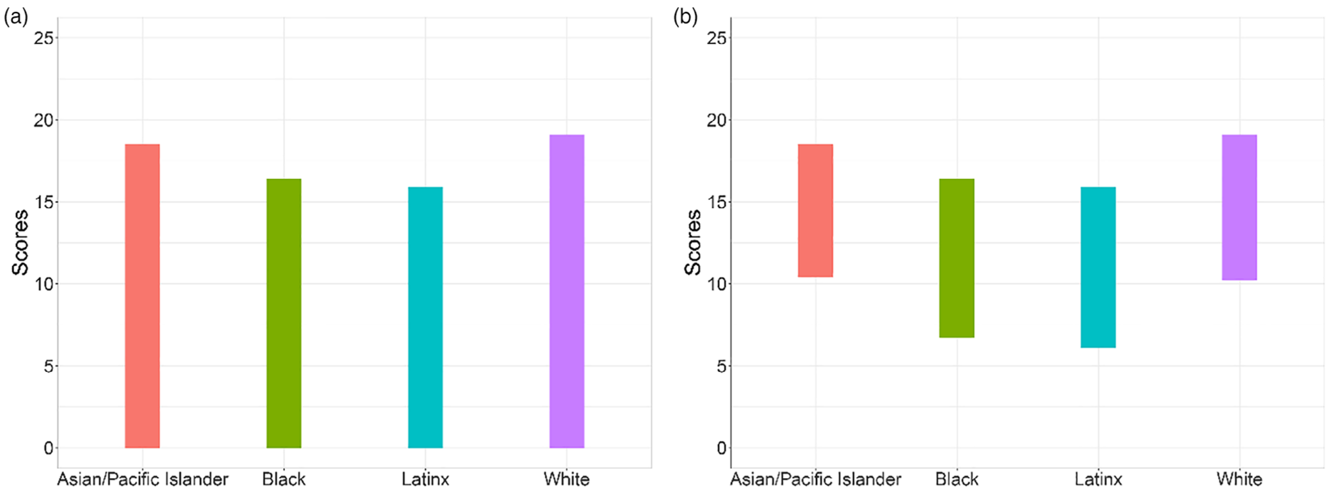

FIGURE 2 (a) Student posttest scores on an assessment by group. (b) Student pre-to-post change scores on an assessment by group [Color figure can be viewed at wileyonlinelibrary.com]

being conveyed. Information visualization research indicates that individuals' visual working memory is relatively limited (Luck & Vogel, 2013), and thus, more complex visualizations will require considerably more processing for readers. In short, displaying information beyond the scope of the core research story may unnecessarily burden readers, particularly those unfamiliar with such visualizations.

A second dimension of inclusivity concerns representation equity within visualizations themselves. Visualizations can perpetuate systemic social inequities (D'Ignazio & Bhargava, 2020; Dörk et al., 2013; Kennedy et al., 2016; Schwabish & Feng, 2020). Two major mechanisms by which visualizations can perpetuate systemic inequities are (1) reinforcing the position, status, and power of dominant social groups and (2) obscuring realities or lived experiences that should have been captured by the visualization. An example of the first mechanism is a visualization that depicts multiple groups and places White students or White men as the first group, implicitly presenting them as the default category to which all others must be compared. A simple redress is alphabetically listing groups (Schwabish & Feng, 2020) to avoid equating the graphical position of dominant groups with their structural position of power and privilege in engineering. An example of the second mechanism is a bar plot depicting *only* posttest learning scores by demographic group rather than depicting pre-to-post change scores. As shown in Figure 2a,b, White students may have the highest posttest scores but also have the highest pretest scores, such that their relative change was similar to or lower than other groups. Hence, showing only posttest scores would give the appearance of White students' overperformance. By always showing pre-to-post changes (change scores), the graphic preserves the meaningful learning

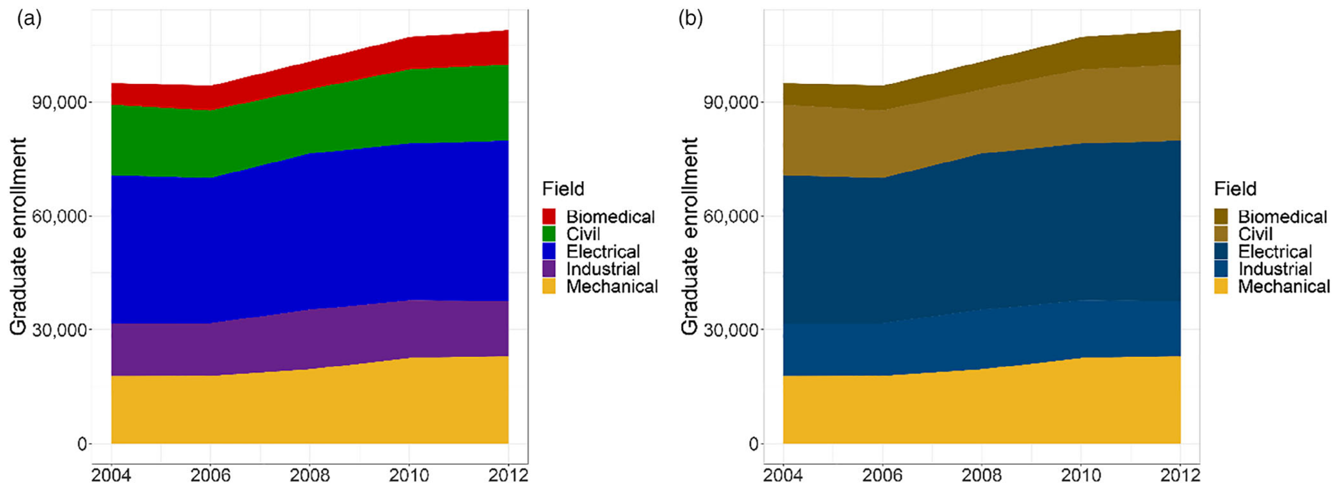

FIGURE 3 (a) Number of students enrolling in engineering graduate majors. (b) The same plot as (a) viewed by those with green CVD

all groups exhibited. Schwabish and Feng (2020) also identify a variety of other ways in which visualizations can challenge or reinforce systemic inequities, including using language and colors with racial equity awareness, considering what groups are missing, questioning default visualization approaches, and exhibiting empathy for visualized populations.

A third dimension of inclusivity concerns readers' physical dis/abilities and differences. Several ways in which dis/abilities affect readers' interactions with visualizations have been documented (Lee et al., 2020; Lundgard et al., 2019). For example, color vision deficiency (CVD) or color blindness can affect readers' ability to interpret visualizations that rely on color to convey information (Relvas, 2018). In addition, low-vision readers may have difficulties understanding visualizations if color contrast, color saturation, and graphic or font sizes are inadequate (Knaflic, 2018). An example of how green CVD affects visualizations is shown in Figure 3a,b, which displays graduate enrollment in five engineering majors. Figure 3b shows how it can be difficult to distinguish the biomedical and civil plot segments as well as the electrical and industrial segments for individuals with green CVD. This effect would be amplified if readers' CVD impacted their ability to see contrast between shades of brown and blue in Figure 3b. Moreover, if the body of the article referred to specific colors in the visualization, for example, "as can be seen in the red segment …," this would not be inclusive of readers with CVD.

Knaflic (2018) provides suggestions on how to address some common challenges for both CVD and other vision impairments. For instance, direct labeling of lines or bars rather than relying on color key alone and running a color blindness simulation test (see Colblindor, 2018) prior to submission can help CVD readers. Using white space between colors and checking color contrasts online prior to submission can help low-vision readers. Publishing companies have an important role to play here and should be more proactive about finding new ways to ensure accessibility to their articles. For example, they should be conscious of factors such as color saturation that affects contrast when making production decisions. They should also explore ways to provide textual descriptions of visualizations that can be read by screen readers or other options for alternative text. While not all journals offer alt-text at the present time due to technology challenges (including the publisher of *JEE*, Wiley), striving for more inclusive solutions should be a goal. At a minimum, detailed textual descriptions of figures could be offered as online supplemental material. For best practices when using alt-text where possible, see Gustafsdottir (2021) and Sollinger (2014). It is worth noting that the visualization community is also addressing accessibility and inclusivity for other challenges, such as blindness (Lee et al., 2020; Lundgard et al., 2019), but those considerations are largely outside the scope of the decision-making of individual engineering education authors and are not limited to visualizations, which are the focus of this editorial.

By critically questioning visualization design decisions, authors, reviewers, and editors can work toward greater inclusivity and equity in engineering education research. To close, we offer a series of questions to help with these decisions. These prompts can help authors reflect on their past choices and, more importantly, can be used prospectively in the design of new visualizations. Below, we provide several broad prompts to consider and a set of prompts for each of the inclusivity dimensions covered above:

General questions

- Why am I including this visualization?
- Is this visualization addressing all of its intended roles/functions?
- Is this visualization fully described in-text and/or with a descriptive caption?
- Have I shared this visual with a colleague(s) unassociated with this work for feedback?

Interdisciplinary audience questions

- Would someone unfamiliar with this visualization format be able to discern what the visualization and any associated text are conveying?
- Does the visualization contain any disciplinary assumptions or conventions scholars from different disciplines may not recognize?
- Is the level of graphical detail on the visualization critical to conveying my core research story and the role the visualization plays in it?

Equitable visualization questions

- Are there ways in which this visualization may reinforce the position or narratives of dominant groups in engineering?
- Are there ways in which this visualization masks or subsumes the lived experiences of any groups depicted?
- Are there any key contextual factors or considerations being left out of the visualization?

Differently abled readers' questions

- Do the coloration aspects, use of white space, and labeling address the abilities of differently abled readers?
- Would the visual lose any crucial information if viewed in grayscale (e.g., black and white print)?
- Are there any viewing devices readers may use that would affect the color palette or resolution and subsequently affect readability?

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