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Board 190: A Mixed-Methods Study of Statistical Thinking in Engineering Practice

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Project Overview

This short report gives an update on the NSF-supported project “ERI: Towards Data-Capable Engineers with a Variability-Capable Mindset” (Grant No. 2138463).

Statistical variability is an important phenomenon to consider for safe engineering design. However, variability is under-emphasized in engineering education, and it is unknown to what degree variability is considered in engineering practice. Our project seeks to understand how practicing engineers respond to statistical variability, and to use these observations to improve undergraduate engineering education.

Recent Work

Our work has better characterized the consideration of variability in engineering education. We conducted a scoping review of engineering textbooks from five large engineering programs, considering 64 unique books [1]. For instance, we found that only 11% of engineering textbooks mentioned “variability,” and that the textbooks mentioned the term “force” ~2.5x as frequently as “uncertainty.” These results help quantify the degree to which variability is under-emphasized in engineering education.

Our work has also fashioned conceptual tools to help understand professional engineering practice. We conducted a qualitative study of practicing engineers’ data analysis approaches. The resulting NAT Taxonomy categorizes choices as either *neglected* (if they neglect variability), *acknowledged* (if they acknowledge the existence of variability), or *targeted* (if they make analysis choices to mitigate the adverse consequences of variability) [2]. The same study found that 23 / 24 participants targeted variability at least once in an hour-long interview protocol. However, the sampling in that study could not support population inference: a large, representative sample would be required, necessitating a survey-based approach.

An ongoing effort in this project is to develop survey-based techniques to measure the prevalence of variability targeting in populations. We describe previous and recent pilot efforts in this vein.

Pilot: Towards Measuring Targeting

This research was determined to be IRB exempt by Brandeis’ IRB under, and followed a human subject protection protocol under #22134R-E.

Previously [3], we reported on pilot efforts to develop a survey-based variability targeting instrument with a student population. In that study, we found that everyday scenarios involving variability were easy to target; we found >90% of participants targeted the consequences of variability for most survey items. These involved scenarios such as bringing sufficient cash to the grocery store, avoiding overdraft charges when writing a check, and leaving on a commute with sufficient time to get to an important meeting.

As part of recruiting participants for another study, we piloted a similar survey with practicing engineers, instead focusing on engineering tasks. Our sample consists of n=54 valid responses from persons who expressed interest in participating in a professional development workshop on data science for engineers. For brevity, we analyze just one task from this survey.

Table 1 reports the data we presented to survey respondents, along with the prompt:

> This data represents the measured ultimate tensile strength (UTS) values of a particular structural metal.
>
> What value of ultimate tensile strength would you use to design parts using this structural metal, such that they would be safe under tensile load?

Table 1. Data presented to participants in study.

Sample	UTS (ksi)
1	32.5
2	33.9
3	30.3
4	30.9
5	26.1
6	27.5
7	28.4
8	31.6
9	29.7
10	29.1

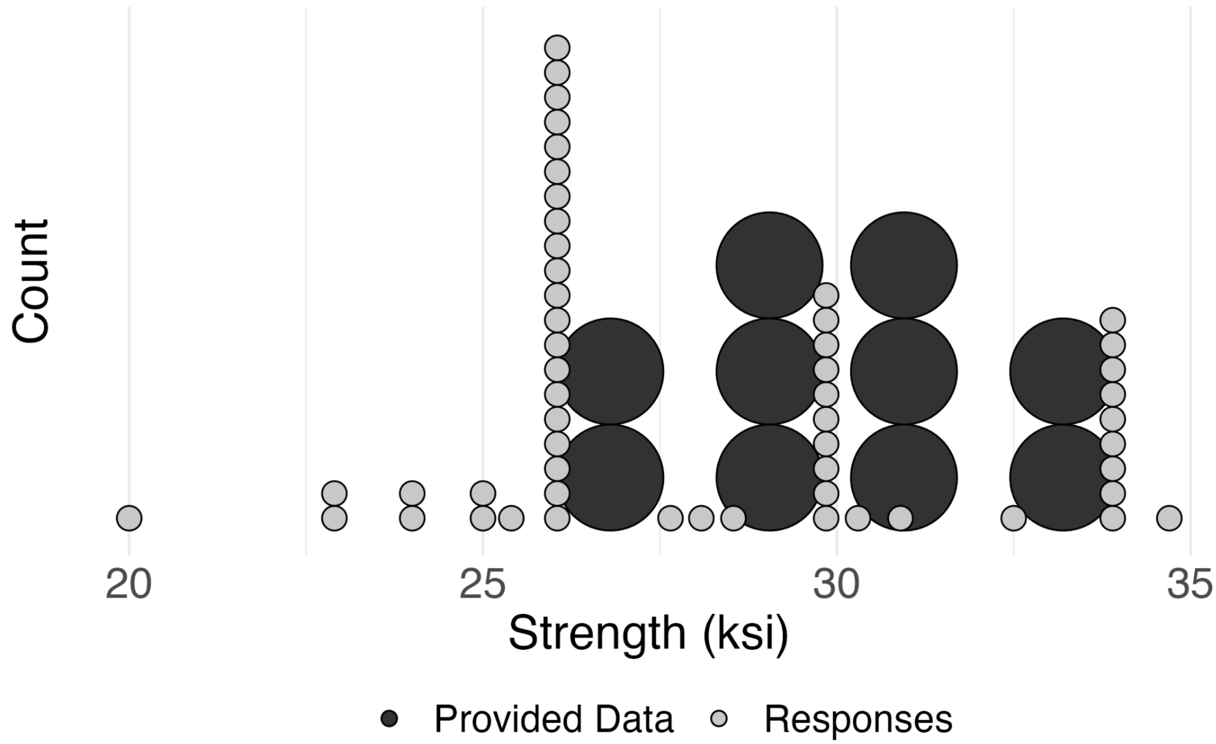

Figure 1. Dotplot of participant Responses, with provided data (see Tab. 1) for reference.

Figure 1 visualizes the sample of survey responses. Given that we did not provide any directions for an appropriate magnitude or degree of conservativeness in design, we elect to treat all responses less than the given data mean as targeted (see Table 2). Note that a slight majority (~57) of responses fall below the mean: Many participants selected the lowest value provided, and some participants selected a value lower than any given data value.

Note also that a sizable fraction (~20%) of participants selected a much *higher* value for design purposes. Without the benefit of interview or free-response data, we can only speculate as to why participants selected a maximally risky option. A large fraction (~22%) of participants selected a value near the data mean. These can be reasonably classified as *neglected* responses.

Table 2. Categorization of responses. Note percentages do not add to 100% due to rounding.

Category	**Count (% of Total)**
Targeted (S < 29)	31 (~57%)
Neglected (29 <= S < 31)	12 (~22%)
Reversed (31 <= S)	11 (~20%)

The results above suggest that, for practicing engineers making decisions with data presented in tabular form, targeting the consequences of variability is relatively difficult: Whereas engineering students readily targeted variability in scenarios with “everyday” variability (>90% of individuals targeted), in this pilot only ~57% of participants targeted variability correctly. It is possible that the ~20% of participants with “reversed” responses were attempting to target variability, and that in a more deliberate setting (i.e., in the workplace), they would have targeted correctly.

Limitations and Future Work

As with the prior study [2], the data for this pilot is drawn from a convenience sample, which limits inference. Furthermore, we presented the participants with very few tasks, so as not to interfere with the primary aim of participant recruitment. We plan to build on this survey-based approach to further develop our ability to measure the targeting of variability in engineering practice.

Our future efforts will deploy the survey with different populations, which we expect to lead to changed results. For instance, younger individuals with less life experience may not target variability even in “everyday” scenarios.

In the long run, we aim to use this study of variability targeting to develop a fundamental understanding of this behavior, with the ultimate aim of improving engineering education. Developing and validating the proposed survey will enable testing of factors that may impact targeting, such as the presentation of data (as a graph or a table) and the framing of a problem. Understanding the impact of these problem features will constitute fundamental understanding to inform engineering education. For instance, a better understanding of the impacts of problem framing will enable us to design educational interventions that encourage students to frame problems in a statistically beneficial way.

References

[1] K. Vo, A. Evans, S. Madan, and Z. del Rosario, “A Scoping Review of Engineering Textbooks to Quantify the Teaching of Uncertainty,” *ASEE Annu. Conf. Expo.*, 2023.

[2] Z. del Rosario, “Neglected, Acknowledged, or Targeted: A Conceptual Framing of Variability, Data Analysis, and Domain Consequences,” *J. Stat. Data Sci. Educ.*, 2024, doi: 10.1080/26939169.2024.2308119.

[3] Z. del Rosario, “A Mixed-Methods Investigation of Engineers Targeting the Consequences of Variability,” presented at the ASEE Annual Conference and Exposition, 2023. [Online]. Available: https://nemo.asee.org/public/conferences/327/papers/36726/view