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Work-in-Progress: Statistical Mindset in Engineering Students

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Abstract

This is a work-in-progress (WIP) paper that investigates the concept and understanding of statistical mindsets among engineering students. In an era defined by data-driven decisions, a robust statistical mindset, which goes beyond academic knowledge to include data interpretation and critical thinking, is crucial. Despite its importance in engineering, where data interpretation and critical thinking are used, there is limited clarity on what this mindset entails. This need motivates the present study to explore and define statistical mindsets in engineering students. This study presents the initial phase of an ongoing investigation with three main objectives: (1) to assess engineering students' understanding of statistical mindset concepts; (2) to define what constitutes a statistical mindset within the engineering student group; and (3) to conduct a preliminary thematic analysis that will inform the development of a rigorous statistical metric for assessing this mindset.

This study employs a qualitative method approach, beginning with the qualitative data collection through an online survey platform called QuestionPro. A total of 38 engineering students from a Western university participated in the study by answering five open-ended questions that were specifically designed and tailored to elicit insights into their perceptions, understanding, and insights toward statistical mindset. Following the data collection, the research progressed to the thematic analysis phase. The preliminary thematic analysis allowed us to identify five recurring patterns and themes in responses, including acknowledging variability and uncertainty, data-driven decision-making, managing complexity in tasks, risk assessment and probability analysis, and confidence in evaluation and application. The findings from this preliminary thematic analysis provide an initial exploration of statistical mindsets among engineering students. Building on these insights, the study offers preliminary implications for the future curriculum redesign in the dimensions of statistical mindset that can be intentionally emphasized in the engineering programs, as well as laying a groundwork for developing a validated assessment tool aligned with engineering accreditation standards. The next step of the research will further explore thematic analysis, considering alternative approaches to ensure the findings extend beyond the structured questions. Moreover, having two or more researchers code the data strengthens inter-rater reliability.

Introduction

In engineering education, fostering a statistical mindset is essential for preparing students to navigate uncertainty, interpret data, and make informed decisions in complex, data-rich environments (Chance, 2002; Garfield & Ben-Zvi, 2008). Essentially, a statistical mindset involves using data and statistical analysis to make decisions and solve problems (Isaac, 2018; Krishnamoorthi, 2010). This approach can have a significant impact on outcomes in engineering education.

As the field of engineering evolves, the ability to effectively interpret and apply data has become a fundamental skill. The increasing reliance on data in engineering design, optimization, and decision-making highlights the importance of cultivating a statistical mindset as a core competency for future engineers (ABET, 2024; Vignola et al., 2017; Wild & Pfannkuch, 1999). Specifically, in engineering practice, statistical reasoning is the foundational knowledge and the bridge to various knowledge domains. To illustrate, it relates to quality control in manufacturing processes, uncertain quantification in wind tunnel experiments, and reliability analysis in safety-related topics such as construction engineering (Coleman et al., 2009; Devore, 2008; Montgomery,2020). These examples, to a certain extent, explain that statistical reasoning is the crucial knowledge for students learning in terms of engineering judgement and design validation.

Through integrating statistical thinking into educational frameworks, students are better equipped to address real-world engineering challenges that demand precision, adaptability, and critical reasoning (Porter, 2020). Building on this background, this WIP paper intends to conduct a preliminary analysis of survey responses using thematic analysis to identify themes, laying the groundwork for future steps.

Literature Review

For engineers addressing modern data-driven challenges, it is increasingly important to develop statistical thinking characterized by critical thinking and the ability to interpret and apply data (Krishnamoorthi, 2010; Lau et al., 2018). To cultivate this mindset effectively, integrating appropriate teaching methods is essential in fostering these skills among students. Studies emphasize teaching approaches that minimize anxiety and foster practical applications, which can be helpful in fostering mindset development (Onwuegbuzie et al., 2010; Pan & Tang, 2004).

Moreover, frameworks like the Guidelines for Assessment and Instruction in Statistics Education (GAISE) recommend active learning methods that can foster productive statistical mindsets and improve academic outcomes (Erhardt & Lim, 2020). Similarly, embedding entrepreneurial mindset principles into statistics courses has led to improved self-regulation, critical thinking, and real-world application of statistical concepts (Bosman & Phillips, 2022). Collectively, these approaches align with broader educational goals, equipping engineering students with the critical thinking and data analysis skills necessary for navigating a data-centric professional landscape.

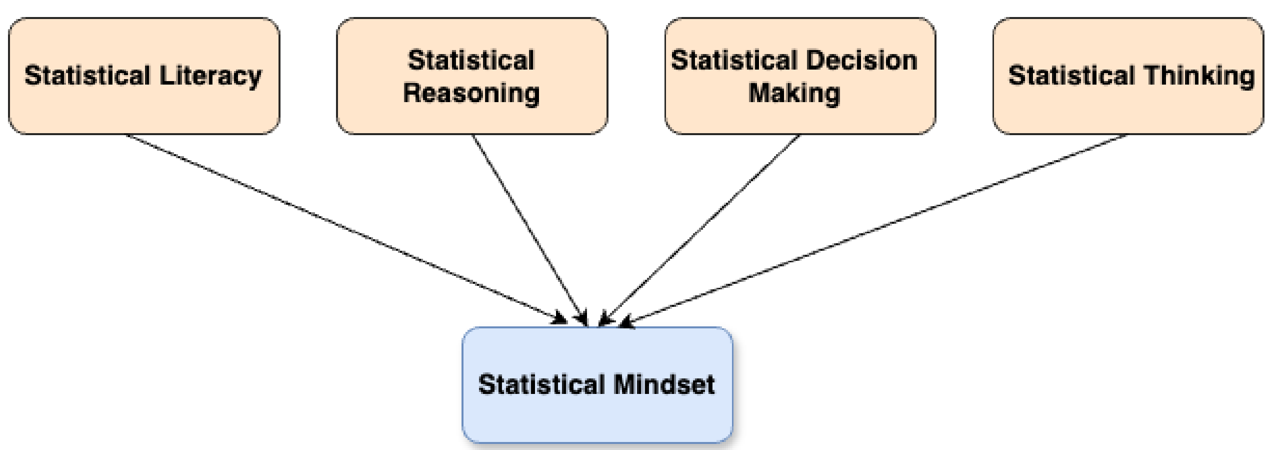
All these mentioned approaches can be used for reference in fostering a statistical mindset. Recent engineering education research also highlights the value of statistical understanding capability in further enhancing statistical reasoning. For example, regression analysis and covariate utilization have demonstrated advantages over traditional methods like ANOVA, offering more precise insights into educational outcomes in engineering contexts (Tan et al., 2024). Moreover, other works have introduced longitudinal and person-centered analysis in engineering education, which has recently been called and applied in engineering education research (Katz et al., 2023; Xu et al., 2023; Xu & Tan, 2023). This further emphasizes the importance of understanding statistics at a higher level. Therefore, it is essential to gain a deeper understanding of a statistical mindset among engineering students in the current data-driven challenges of modern engineering practices, bridging the gap between theoretical knowledge and practical application.

Conceptual Framework

Adopting a statistical mindset requires a good understanding of its core concepts. It is a cognitive framework that helps engineers effectively make use of data to make informed decisions and apply statistical reasoning in problem-solving. According to Garfield and Ben-Zvi (2008), a statistical mindset consists of four main components: statistical literacy, statistical reasoning, statistical thinking, and statistical decision-making. Statistical literacy refers to the ability of a person to understand and interpret statistical data presented in different formats and statistical reasoning is the ability to explain statistical concepts, methods, and results. Statistical thinking comprises an understanding of statistical processes, including data collection, analysis, and interpretation, while statistical decision-making involves using evidence to make good choices in uncertain situations.

These components form the basis of understanding how engineering students engage with statistical data and apply it to solve problems in academic and professional settings. **Figure 1** shows a conceptual framework diagram summarizing the statistical mindset's components.

Figure 1
Conceptual Framework Diagram



Differentiation from Six Sigma

In engineering, Six Sigma and a statistical mindset serve different purposes despite their common traits as data-driven approaches. It is important to know the difference between these two concepts. The concept of Six Sigma originated from Motorola in the 1980s and has been used across industries to enhance quality control, operational performance, and decision-making (Anthony, 2006). It is a structured methodology focusing on improving processes and reducing defects. On the other hand, a statistical mindset is broad and interdisciplinary, and is applicable to diverse fields. The statistical mindset enables adaptability, fostering critical thinking and problem-solving skills that transcend the structured framework of Six Sigma. Table 1 highlights the key difference between these two concepts. While Six Sigma provides a structured methodology for process improvement, a statistical mindset represents a basic statistical cognition-oriented approach that is used to guide students in engineering fields to acquire these skills and to master and apply them across diverse engineering contexts. In this sense, a statistical mindset can be viewed as a foundation and transferable knowledge across various contexts, and Six Sigma serves as one of the structured applications for statistical reasoning.

Table 1
Key Differences of Six Sigma and Statistical Mindset

Aspect	Six Sigma	Statistical Mindset
Purpose	Process optimization	Decision-making framework
Scope	Specific project-based tasks	Broad, interdisciplinary
Emphasis	Methodology	Cognitive skills

Methods

Methodology & Data Analysis

This study employs a qualitative research approach to explore how engineering students develop a statistical mindset in their academic and professional experiences. The thematic analysis framework proposed by Braun and Clarke (2006) was used to analyze qualitative responses. This approach allowed for the identification of patterns and themes within the data, which provided a nuanced understanding of participants' perspectives regarding statistical mindset.

Participants and Recruitment Methods

The study recruited 38 undergraduate engineering students enrolled in introductory statistics courses at a Western university. A convenience sampling strategy was used, where instructors distributed the survey link via email to their students. Participation was voluntary, and informed consent was obtained from all respondents prior to completing the survey. The study was approved by the Institutional Review Board (IRB) of the lead author's institution, ensuring compliance with ethical research guidelines. As a preliminary investigation, this study did not collect participants' demographic information, but all the participants were recruited from a first-year engineering statistical class.

Procedure

Qualitative data were collected through an online survey administered via QuestionPro, comprising five open-ended questions. The survey was conducted remotely, with no restrictions on the participation environment. Participants first needed to complete the consent before proceeding to five open-ended questions. There was no time limit for answering these questions. Once all questions were answered, the experiment was completed.

Preliminary Findings

The thematic analysis process, which involved coding of the survey data, revealed five themes that were inspired by the research questions. These themes showed the perceptions of engineering students in using statistical reasoning in solving problems. The emerging themes are (1) variability and uncertainty, (2) using data as a decision-making tool, (3) managing complexity through structured approaches, (4) balancing risk and probability in decision making, and (5) developing confidence in data evaluation and its application. Table 2 presents these themes with their representative codes and some students' responses to the survey questions.

Table 2
Themes Identified and Example Responses from Survey Data

Survey Question	Theme	Code Name	Sample Response
Q1: How do you perceive the role of variability and uncertainty in engineering practices?	Navigating Variability and Uncertainty	Variability guides decision-making	"Variability and uncertainty are intrinsic to engineering practices, influencing design, analysis, risk assessment, and overall project outcomes."
		Uncertainty requires adjustments	"Uncertainty is the reassurance of engineering that nothing will function as planned. Nothing is perfect; it would need to be modified, adjusted, or corrected."
Q2: How do you feel data or results shape your decision-making in engineering contexts?	Data as a Decision-Making Tool	Data is essential for informed engineering decisions	"Data should be, and most often is, the core of an engineer's decision-making process. Engineers are trained to record, organize, and analyze data to decide upon a course of action."

		Data supports and validates new designs	"I think it's important to have data backing up your design."
		Decisions without data are guesses	"Making decisions without any data or results to back them up are essentially guesses made with little to stand on."
Q3: How do you approach situations in engineering where multiple variables or factors interplay?	Managing Complexity through Structured Approaches	Critical thinking and knowledge of variable impacts	"For my project, we consider many factors, not only in physical design but how they interact electrically."
		Systematic planning and testing of variables	"I like to list variables and test one at a time if possible."
		Collaboration ensures design functionality	"To ensure our product interacts correctly, we plan ideas in collaboration, even if it gets confusing at times."
Q4: How do your personal perceptions of risk and probability guide your decision-making in engineering tasks?	Balancing Risk, Probability, and Decision-Making	Decision-making balances risk and reward	"Deadlines significantly influence my choices; if time allows, I might explore lower-probability options, while approaching deadlines often lead me to opt for safer choices."
		Decisions account for uncertainties and consequences	"If the risk of consequence outweighs the probability of success, I would opt to discontinue pursuit of an engineering solution or task."
		Probability and risk should guide decision-making	"The more I can understand the probability of outcomes, the better I can make decisions to minimize risks."

Q5: How confident are you in your ability to evaluate and apply data in engineering situations?	Confidence in Data Evaluation and Application	Confidence rooted in learning and experience	"I consider myself to have good capabilities, which are based on my years of learning and work experience that have shaped my self-assurance."
		Confident but recognizes the pressure of judgment	"I am confident in my ability to assist and provide insights, but it is immense pressure to exercise judgment when applying data-driven approaches in real-world engineering scenarios."
		Limited confidence but acknowledges the importance of data evaluation	"I wouldn't say I am super confident at applying and evaluating data in engineering situations, but it is a very important step when prototyping."

1. Navigating Variability and Uncertainty

An emerging theme from the analysis shows that variability and uncertainty play a crucial role in engineering solutions. From the insight, variability is seen as a guiding and design-making tool for bringing out engineering solutions. Uncertainty on the other hand, emerged as a challenge that requires an iterative process to manage its impacts. The ability of students to recognize the challenges of uncertainty in engineering solutions shows a shift towards analytical reasoning to solve real-world problems. In addition, from the data, statistical and probabilistic analyses are essential for solving the problems uncertainty brings in the development of engineering solutions. Together, these insights and themes agree with the already existing mechanisms of engineering professionals which involve using modeling and risk assessment to make decisions in uncertain circumstances in the engineering solution process.

2. Data as a Decision-Making Tool

The second theme is evidence of the role data play in making decisions in engineering field. Responses from students demonstrates that they rely on data to justify their choices, including validating assumptions to arrive at better outcomes. As stated by one of the students,'
"Data should be, and most often is, the core of an engineer's decision-making process. Engineers are trained to record, organize, and analyze data to decide upon a course of action." It reflects the evidence-based and practical reasoning approach in engineering. Data as a decision-making tool is a theme that challenges students to also understand data as a tool for innovation. It provides engineering students with the ability to produce ideal designs, and to assert the consequences of

the choices they make. Therefore, this theme supports and promotes data literacy in engineering education and encourages students to develop skills to enable them to analyze and interpret data.

3. Managing Complexity through Structured Approaches

The third theme highlights the approach students use in managing complexity through systematic planning, critical thinking, and collaboration. Several responses emphasized breaking down engineering problems into manageable components, with many students using iterative testing, and variable isolation techniques. Others highlighted collaborative efforts in engineering design, where teamwork ensures that interacting factors are accounted for. This theme indicates that students are developing a methodical approach to problem-solving for example one student stated that, "……...we consider many factors, not only in physical design but how they interact electrically."

4. Balancing Risk, Probability, and Decision-Making

Risk management is an important aspect of engineering, and students demonstrated that probability influences their decision-making processes. The theme shows a good synergy of how they balance risk and reward, by citing different scenarios such as handling assignment deadlines constraints and the likely consequences. For example, one student stated that "Deadlines significantly influence my choices; if time allows, I might explore lower-probability options, while approaching deadlines often lead me to opt for safer choices." Their emphasis on how probability guide their decision-making suggests that they recognize the importance of statistical reasoning on issues relating to professionalism and judgements. Some students stated that low probability of events that may lead to high impact risk require careful consideration. This shows that they understand how to manage risk in fields like safety engineering, manufacturing, and infrastructure development.

5. Confidence in Data Evaluation and Application

The last theme emphasizes the importance of practical learning as a tool for boosting students' confidence in data analysis and its applications. Many students showed that they are highly confident in their abilities to handle statistical data. They mentioned that their confidence was mostly contributed by practical learning through internships and statistical simulations shaped However, some students still face challenges, especially when faced with complex real-world problems. This indicates the importance of applied data analysis, simulation-based learning, and industry collaboration to bridge the gap between theoretical knowledge and real-world practice.

Conclusion & Limitations

The study highlights the significance of fostering a statistical mindset among engineering students to equip them for the growing reliance on data-driven decision-making in professional practice. The preliminary thematic analysis revealed insights into how students perceive uncertainty, utilize data for decision-making, manage complexity, assess risk, and develop confidence in statistical reasoning**.** These findings provide an initial understanding of how students engage with statistical concepts and the challenges they encounter in achieving fluency in data analysis and interpretation.

As this paper is currently in progress, many details require further refinement and expansion of work. First, it is important to more clearly define the relationship between emergent themes and the analysis guided by research questions, while further examining the diversity and complementarity of the data. Specifically, the current themes were potentially influenced by the framework embedded in the survey design, which raises important considerations about the nature of thematic emergence. Therefore, the next step of the work can be incorporating a more open-ended thematic analysis to capture additional insights beyond those directly prompted by the survey. Moreover, the version of coding was conducted by a single researcher, which may introduce subjectivity and bias in coding and theme identification. Without inter-rater reliability measures, some interpretations may reflect individual perspectives rather than objective patterns. Moving forward, the full paper should incorporate peer review and coder agreement processes to strengthen the credibility of findings.

Future Directions

Through this research and the preliminary findings from the thematic analysis, we seek to create a reliable and valid measurement tool to evaluate the statistical mindset among engineering students. This measurement metric aims to bridge the gap between theoretical understanding and practical application in higher education engineering education settings. Also, this proposed measurement instrument may support program-level assessment aligned with ABET criteria that emphasize probability and statistical competencies in engineering curricula. Moreover, this study provides a certain level of insight to advance educational practices that prepare engineering students for the current fast-developing artificial intelligence era and data-centric challenges. Furthermore, the research will identify areas of strength and opportunities for enhancement, guiding targeted interventions and teaching pedagogical strategies toward engineering students in the higher education systems. In a nutshell, this study embarks on defining and measuring the statistical mindset through qualitative inquiry and thematic analysis. It also aims to lay a foundation for future research steps in terms of creating rigorous measurement tools and understanding the mindset corresponding to the teaching pedagogies.

References

ABET. (2024). Criteria for accrediting engineering programs, 2025–2026. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2025-2026/

Antony, J. (2006). Six sigma for service processes. *Business Process Management Journal*, *12*(2), 234–248. https://doi.org/10.1108/14637150610657558

Bosman, L., Shirey, K., & Fernhaber, S. (2023). Plenary: A perspectives approach - Integrating the entrepreneurial mindset into the engineering classroom. *2023 IEEE World Engineering Education Conference (EDUNINE)*, 1-2. https://doi.org/10.1109/edunine57531.2023.10102911

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, *3*(2), 77-101.

Chance, B. L. (2002). Components of Statistical Thinking and Implications for Instruction and Assessment. *Journal of Statistics Education*, *10*(3). https://doi.org/10.1080/10691898.2002.11910677

Coleman, H. W., Steele, W. G., & Coleman, H. W. (2009). *Experimentation, validation, and uncertainty analysis for engineers* (Vol. 3). Hoboken, NJ: John Wiley & Sons.

Devore, J. L. (2008). Probability and Statistics for Engineering and the Sciences.

Erhardt, E. B., & Lim, W. (2020). Effects of a GAISE-based teaching method on students' learning in introductory statistics. *Communications for Statistical Applications and Methods*, *27*(3), 269-284. https://doi.org/10.29220/csam.2020.27.3.269

Garfield, J. B., Ben-Zvi, D., Chance, B., Medina, E., Roseth, C., Zieffler, A., ... & Zieffler, A. (2008). Creating a statistical reasoning learning environment. *Developing students' statistical reasoning: Connecting research and teaching practice*, 45-63.

Isaac. M (2018), Mindset, Attitudes, and Success in Statistics. Undergraduate Honors Capstone Projects. https://doi.org/10.26076/dd12-1cfc

Katz, A., Godwin, A., & Brozina, C. (2023). Advanced Considerations in Quantitative Methods for New Directions in Engineering Education Research. In *International Handbook of Engineering Education Research* (pp. 660-689). Routledge.

Krishnamoorthi, K. S. (2010, October). Statistical thinking for engineers-what, why, and how?. In *2010 IEEE 17Th International Conference on Industrial Engineering and Engineering Management* (pp. 893-897). IEEE.

Lau, F. D. H., Adams, N. M., Girolami, M. A., Butler, L. J., & Elshafie, M. Z. (2018). The role of statistics in data-centric engineering. *Statistics & Probability Letters*, *136*, 58-62.

Montgomery, D. C. (2020). *Introduction to statistical quality control*. John wiley & sons.

Onwuegbuzie, A. J., Leech, N. L., Murtonen, M., & Tähtinen, J. (2010). Utilizing mixed methods in teaching environments to reduce statistics anxiety. *International Journal of Multiple Research Approaches*, *4*(1), 28-39.

Pan, W., & Tang, M. (2004). Examining the effectiveness of innovative instructional methods on reducing statistics anxiety for graduate students in the social sciences. *Journal of Instructional Psychology*, *31*(2).

Porter, T.M. (2020). The Rise of Statistical Thinking. 1820-1900. Princeton University Press

Tan, L., Wei, S., Xu, X., & Morphew, J. (2024). The advantage of regression and covariate utilisation over ANOVA in engineering education research. *European Journal of Engineering Education*, 1-31.

Vignola, C., London, J., Ayala, R., & Huang, W. (2017, October). Cultivating an entrepreneurial mindset in an undergraduate engineering statistics course using project-based learning. In *2017 IEEE Frontiers in Education Conference (FIE)* (pp. 1-4). IEEE.

Wild, C. J., & Pfannkuch, M. (1999). Statistical thinking in empirical enquiry. *International statistical review*, *67*(3), 223-248.

Xu, X., & Tan, L. (2023, June). A Bayesian Approach to Longitudinal Social Relations Model. In *2023 ASEE Annual Conference & Exposition*.

Xu, X., Wei, S., & Tan, L. (2023, October). Expanding Quantitative Approaches in Engineering Education Research: Embracing Empirical Bayes for Longitudinal Person-Centered Analysis. In *2023 IEEE Frontiers in Education Conference (FIE)* (pp. 1-6). IEEE.