

Navigating the Unknown: Work-In-Progress on Ambiguity, Uncertainty, and Students' Tolerance in Capstone Projects

Hrushikesh Godbole¹ and Elizabeth A. DeBartolo²

¹*The Ohio State University*

²*Rochester Institute of Technology*

Future engineers must learn to navigate ambiguity and uncertainty in real world engineering work, and the capstone course is a prime course to learn these skills. This research explores how ambiguity and uncertainty appear in capstone projects and what can be learned about popular instruments to measure students' tolerance for ambiguity (TA) and tolerance for uncertainty (TU). Analysis of interviews with capstone project advisors revealed that ambiguity arises from incomplete problem or solution understanding, and uncertainty arises from missing parameter thresholds needed for defining and assessing design choices. Further, sources of student perceived ambiguity and uncertainty were identified, and design process tasks were mapped to reduction of ambiguity and uncertainty. Analysis of TA measures showed low reliability for the most frequently used TA scale, promise for MSTAT-II, and a moderate correlation between TA and TU.

Keywords: Ambiguity, uncertainty, tolerance to ambiguity, tolerance to uncertainty

Corresponding Author: Elizabeth A. DeBartolo, eademe@rit.edu

Motivation

Undergraduate engineering students attend university not only to become qualified engineers who will routinely work to solve complex ill-structured problems, but also to develop into responsible adults capable of thriving in a world marked by increasing volatility, uncertainty, complexity and ambiguity. Therefore, engineering education must foster qualities such as tolerance for ambiguity and adaptability, which transcend traditional engineering learning outcomes¹. The ability to navigate ambiguity and uncertainty is a critical skill that must be developed among engineering students, and this often happens in the capstone course. In a preliminary study, when capstone instructors were asked about risk factors affecting student learning outcomes, they frequently called out the ability to overcome ambiguity and uncertainty². Low performing capstone teams struggled with the vague nature of problems, difficulty of work, and the significant time commitment that was required, while higher-performing teams embraced the ambiguity, finding value in the freedom to interpret the problem and the flexibility to shape their own solution paths³.

By engaging students in the engineering design process of converting ill-defined problems into implementable solutions, the capstone course creates a structured environment for addressing ambiguity and uncertainty. To explore this premise, this paper conducts

an initial exploration into ambiguity, uncertainty, tolerance to ambiguity (TA), and tolerance to uncertainty (TU) in the capstone context. Two research questions kick off this initial exploration.

RQ1: What distinguishes ambiguity from uncertainty in engineering capstone design, and in what project contexts does each arise?

RQ2: How could TA and TU be measured in capstone students?

Literature Review

Research Question 1

In a technical problem-solving context, uncertainty describes cases where the parameters of the problem are known, but their exact values are not defined⁴. Ambiguity describes situations where the structure of the problem is unclear, including relevant parameters, how they relate to one another, and what procedure should be used to reach a solution⁴.

With the goal of capturing a range of perspectives rather than a single 'right' one, a team of researchers interviewed students and practicing engineers to map out the distinct ways people think about and deal with ambiguity in engineering problems⁵. However, this group did not define ambiguity for the interviewees, which limits the ability to distinguish between ambiguity and uncertainty.

In another study, students' perceptions of whether assignment expectations were clear or ambiguous were assessed by asking students to self-report their ability to recall, explain, independently implement, and integrate or adapt knowledge⁶. This approach measured both uncertainty and ambiguity as per Blooms' taxonomy, but no distinction was made between the two concepts.

In summary, there is evidence in scholarly literature suggesting a difference between the conception of ambiguity and uncertainty in the context of technical problem solving. Yet limited work has been done in characterizing ambiguity and uncertainty in the engineering capstone context.

RQ 2: Tolerance to Ambiguity and Uncertainty

Several authors have explored the implications of student TA and/or TU. Mohammed et al. used the MSTAT-I instrument in a first-year engineering course and found that TA correlated positively with overall team efficacy for open-ended projects but found no significant correlation directly between TA and team performance⁷. The authors acknowledged that low n's may have impacted their results. Godbole, et al.⁸ used Budner's intolerance to ambiguity instrument⁹ and Freeston's "why people worry" scale¹⁰ to study correlations between students' TA and TU, and capstone team design output, showing that a high TA is correlated with better design project outcomes⁸. This study also called out low response rates, which may have been due in part to survey fatigue. Finally, Hertz investigated whether self-efficacy and tolerance to ambiguity were impacted by instructional strategies, using a custom-developed set of survey questions. Results showed that some open-ended activities improved tolerance to ambiguity¹¹.

A variety of instruments are available to measure tolerance to ambiguity (TA) and tolerance to uncertainty (TU). A 2013 literature review acknowledged the evolution of the concept of tolerance to ambiguity over the years¹², noting that Budner's TA instrument⁹ is known for low internal consistency, yet it is widely cited. Budner's instrument, developed for the psychology field, includes 16 questions and captures tolerance to three dimensions of ambiguity: novelty, insolubility, and complexity. Herman, et al.¹³ proposed eliminating several questions from Budner's scale. In the capstone context, some of these eliminated questions could have been particularly problematic if left in, because the nature of a capstone course is to teach students how to solve problems in the face of ambiguity rather than to become comfortable with ambiguity. For example, one survey item states, "*In the long run it is possible to get more done by tackling small, simple problems rather than large and*

complicated ones." According to the survey, disagreement reflects a high tolerance for ambiguity. However, in the capstone course students are explicitly taught to manage complex problems by breaking them down into simpler components. Based on the survey's wording, students who apply these design process tools would likely respond in a way that suggests a lower tolerance for ambiguity.

The trade-off between validated and reliability-proven survey instruments and tweaking the instrument to better align with context is highlighted by a recent capstone study that reported changing the wording of 23 of the 32 items on their TA instruments to ensure face validity¹⁴. The MSTAT-I scale preserved the novelty, insolubility, and complexity factors laid out by Budner. The revised MSTAT-II scale is shorter and is designed to measure ambiguity as one core idea rather than a concept with multiple dimensions. Despite having fewer questions, it maintains a high internal consistency. Thus, it offers a promising compromise¹⁵.

Analysis Methods

Research Question 1

In this study, we looked at recurring ideas and patterns in prior literature. Then, using what we know from teaching practice, we examine the meaning of ambiguity and uncertainty in engineering capstone projects. The purpose of the methodology is not to measure student outcomes or prevalence, but to clarify and structurally distinguish these constructs as they manifest in capstone design work. The resulting framework is intended to support conceptual understanding and future empirical investigation. First, definitions of ambiguity and uncertainty from technical problem solving and engineering design literature were reviewed to establish distinctions between the two concepts. Second, empirical studies examining how students experience ambiguity and uncertainty were analyzed. In parallel, common instructional practices and student activities in engineering capstone courses were examined based on established capstone practices at authors' universities and the authors' experience with multidisciplinary capstone instruction.

Research Question 2

A body of data gathered during a prior study was used for this analysis⁸, using Budner's TA instrument⁹ and Freeston's TU instrument¹⁰. Since the internal consistency for Budner's TA instrument in this study was low, we analyzed Budner's instrument by dimension (Novelty, Insolubility, and Complexity) to explore whether a subset might provide useful insights. TA using

Herman's reduction¹³ was also used, as it eliminates questions from Budner's instrument that may be problematic in the capstone design context, and has been shown to improve internal consistency. Since ambiguity and uncertainty are closely related, it is also worth exploring whether student TA and TU are correlated. If they are correlated, insights into potential student risk factors could still be identified while requiring fewer student surveys. Establishing acceptable internal consistency supports the validity of subsequent correlation analysis between TA and TU. To examine the association between TA and TU, Pearson's correlation coefficient was calculated.

Findings and Discussion

Research Question 1

Several instances of sequential ambiguity and uncertainty were noted in interviews by the author with capstone instructors². For example, in one medical device project, a student team struggled for weeks because they failed to interpret tacit medical requirements such as a surgeon's description of applying a "medium amount of force." After instructor intervention, it became clear that a test fixture would be required. This is a case of ambiguity since a parameter of the design problem of needing to characterize force was not recognized. Once the simple test fixture was constructed, it was straightforward to reduce the uncertainty around the exact amount of force.

Drawing on such prior literature in engineering design and capstone pedagogy, as well as common patterns in capstone project practice, we propose a four-stage analytical lens based on the objective of the capstone work at a given stage in the project. The four stages are: reducing problem ambiguity, reducing problem uncertainty, reducing solution ambiguity, and reducing solution uncertainty. These can be seen as sequential objectives within problem space and solution space as seen in Figure 1, which also lists sample activities to reduce uncertainty and ambiguity during each stage.

Similar activities may serve different purposes across stages, and the framework is intended as an interpretive lens rather than a prescription of student activity. For example, prototyping may be done to elicit early customer feedback to refine understanding of the problem and to evaluate two alternatives of a subsystem to achieve a desired functionality.

In addition, students may experience this ambiguity and uncertainty differently depending on a variety of factors: 1) how clear the next steps are to the students, 2) what intermediate artifacts are required to continue progressing, 3) where to look to increase project-related

knowledge, and 4) how individuals and teams respond when faced with ambiguity and uncertainty. Further, it was observed that constraints such as time, budget, and staffing tend to amplify the perceived ambiguity and uncertainty.

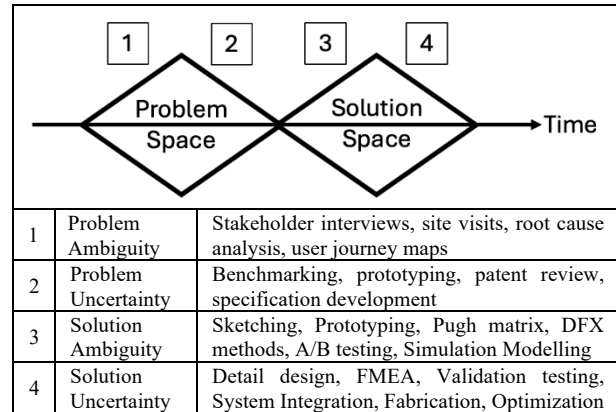


Figure 1: Sequential project objectives with sample activities

For RQ1, we found that in capstone design work, ambiguity arises from an incomplete understanding of what the problem entails or what form an appropriate solution should take, while uncertainty results from lacking knowledge of the parameter thresholds within either the problem or the solution space that are needed to define, compare, or validate design choices.

Research Question 2

Table 1 summarizes the internal consistency results for the tolerance to uncertainty (TU) and tolerance to ambiguity (TA) instruments. The TU instrument demonstrated high internal consistency ($\alpha = 0.92$), indicating reliable measurement within the engineering student sample. In contrast, Budner's TA instrument showed low internal consistency ($\alpha = 0.44$), with internal consistency for each dimension ranging from $\alpha = 0.20$ to $\alpha = 0.36$.

The analysis does not indicate that there is a particular dimension of TA that provides better internal consistency than Budner's instrument overall. Looking at a reduced version of Budner's scale proposed by Herman did improve internal consistency slightly ($\alpha = 0.52$) and this reduced question set was used for correlation analysis.

A comparison of TU and TA (Herman's reduction) results reveals a moderate correlation ($r = 0.40$). For the proposed model of ambiguity and uncertainty during the problem and solution phases of a typical capstone project, this means that, while the two may be related, both parameters may still be important when identifying instructional strategies to promote student success.

For RQ2, we found that even though TA and TU do show moderate correlation in capstone students, Budner's instrument does not have suitable internal consistency, and therefore we recommend exploring the MSTAT II instrument for future work.

Table 1. Internal consistency for TA, TU instruments

Instrument	Alpha
Intolerance of Uncertainty (TU)	0.92
Budner's instrument (TA)	0.44
Novelty	0.20
Insolubility	0.25
Complexity	0.36
Herman's Reduction	0.52

Limitations & Future Work

Low internal consistency in the TA instrument may limit the ability to detect meaningful relationships. For future work, the MSTAT-II is recommended, as it draws a balance between survey length and internal consistency, and its predecessor has been used in prior investigations involving engineering students. IRB approval has been secured to administer the MSTAT-II instrument to assess internal consistency for engineering capstone design students. If successful, MSTAT-II will be administered as a pre- and post-capstone survey to begin investigating whether previously identified correlations stand, and whether strategies taught in capstone improve students' TA.

It is recognized that the four-stage framework and the sources of ambiguity and uncertainty are work-in-progress research artifacts which require further elaboration and synthesis. This work also motivates the development of a rubric or scaled instrument to measure experienced ambiguity and uncertainty in engineering capstone projects which includes dimensions representing the identified sources.

Lastly, this study is limited by reliance on literature, prior data, and teaching practice rather than primary data, and institution-specific capstone contexts. Empirical validation and examination of broader generalizability left for future work.

References

- Atman, C. J., Sheppard, S. D., Turns, J., Adams, R. S., Fleming, L. N., Stevens, R., . . . Leifer, L. J. (2010). *Enabling Engineering Student Success: The Final Report for the Center for the Advancement of Engineering Education*.
- Godbole, H. C. (2025). *Analytics of Capstone Projects: Understanding Outcomes Through People, Products, And Processes* (Doctoral dissertation, Rochester Institute of Technology)

- Jaeger-Helton, K., & Smyser, B. M. (2017, June). *Switching midstream, floundering early, and tolerance for ambiguity: How capstone students cope with changing and delayed projects*. In *2017 ASEE Annual Conference & Exposition*.
- Schrader, S., et al. (1993). Choice over uncertainty and ambiguity in technical problem solving. *Journal of Engineering and Technology Management*, 10(1-2), 73-99.
- Douglas, E. P., et al. (2022, October). Comparing Engineering Students' and Professionals' Conceptions of Ambiguity. In *2022 IEEE Frontiers in Education Conference (FIE)* (pp. 1-4). IEEE.
- Pereira Pessoa, M. V. (2023). Guidelines for teaching with ill-structured real-world engineering problems: insights from a redesigned engineering project management course. *European Journal of Engineering Education*, 48(4), 761-778.
- Mohammed, S., et al. (2006, June). *Tolerance for ambiguity: An investigation on its effect on student design performance*. In *2006 Annual Conference & Exposition* (pp. 11-1343).
- Godbole, H., et al. (2023, June). Impact of Student/Team Characteristics on Design Project Outcomes in Senior Design Courses. In *ASEE Annual Conference proceedings*.
- Stanley Budner, N. Y. (1962). Intolerance of ambiguity as a personality variable 1. *Journal of personality*, 30(1), 29-50.
- Freeston, M. H., et al. (1994). Why do people worry?. *Personality and individual differences*, 17(6), 791-802.
- Hertz, J. L. (2018, June). Confidently uncomfortable: first-year student ambiguity tolerance and self-efficacy on open-ended design problems. In *2018 ASEE Annual Conference & Exposition*.
- Furnham, A., & Marks, J. (2013). Tolerance of ambiguity: A review of the recent literature. *Psychology*, 4(09), 717-728.
- Herman, J. L., et al. The Tolerance for Ambiguity Scale: Towards a more refined measure for international management research. *International Journal of Intercultural Relations* 34, 58-65 (2010).
- Brisbane, J., & London, J. (2022). WIP: A Pedagogical Intervention Leveraging Engineering Design Thinking to Foster a Tolerance for Ambiguity. *Review directory American Society for Engineering Education*.
- McLain, DL. Evidence of the properties of an ambiguity tolerance measure: the Multiple Stimulus Types Ambiguity Tolerance Scale-II (MSTAT-II). *Psychol Rep.* 2009 Dec;105(3 Pt 1):975-88. doi: 10.2466/PR0.105.3.975-988. PMID: 20099561.