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Board 119: WIP: Three Scaffolding Approaches to Foster a Tolerance for Ambiguity in an Undergraduate Engineering Statistics Course

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WIP: Three Scaffolding Approaches to Foster a Tolerance for Ambiguity in an Undergraduate Engineering Statistics Course

Society is becoming increasingly data driven. This is evidenced by the U.S. Bureau of Labor Statistics reports that indicate that the job outlook for occupations focused on data analysis is growing at an above-average rate [1]. This increased demand for a workforce with strong analytical skills includes the engineering profession because of a corresponding growth in the amount of data surrounding the types of problems engineers are asked to address.

Fourteen major challenges were outlined by the National Academy of Engineering in their area, that range from issues as pervasive as energy, as fundamental to human life as clean water, and as intimate as personalized learning [2]. Each of these challenges is complex, requires interdisciplinary expertise, and is filled with elements of uncertainty. In many ways, they exhibit the quintessential characteristics of what most designers call a "wicked problem"—problems involving multiple stakeholders with conflicting priorities, incomplete information that is only clarified by beginning to solve it, and that result in solutions that are deemed better or worse rather than right or wrong [3]. Though varied in nature, there is at least one thing that unifies these problems and another that unifies the people that solve them. Data is what unifies these problems: no matter the problem type, large, messy datasets are used to understand the nature of the problem and whether or not a proposed solution is working to address it. Moreover, the nature of the underlying data themselves is varied and the number of technical approaches needed to appropriately analyze these large datasets is equally varied. Similarly, design thinking is what unifies the engineers that solve these problems: regardless of what type of engineer is involved, engagement in the engineering design process is what unifies those solving complex engineering problems [4], [5], [6]. The design process offers a framework for defining problems in the context of constraints, coming up with a variety of potential solutions, choosing the best ones, developing those solutions, testing them iteratively, and effectively showing the results [4], [7].

An emphasis on the design process is already an essential part of undergraduate engineering education. However, current approaches to teaching engineering design are largely centered around the development of a physical artifact. It is discussed that engineering design's potential to be used as a mechanism for struggling with the ambiguity embedded in data-driven problems is very unexploited. As part of addressing data-driven problems, engineering students will need to comprehend the contextual elements surrounding data sets, deal with insufficient information, and deal with problems that have several acceptable answers. They must be able to select the best analytical technique for the situation and apply it properly. Also, it is crucial that students develop their ability to assess data, describe the practical consequences of those outcomes, and successfully communicate their findings to decision-makers. Unfortunately, the current approach to teaching engineers about data does not account for the ambiguity they will encounter when working on real-world problems; however, design thinking has the potential to bridge this gap. The engineering design process is rarely thought of as a mechanism that can be used to deal with the uncertainty inherent in solving data-driven problems, but the goal of our research is to investigate its potential to do it.

Much of the existing scholarship on engineering design is centered on the development of a physical artifact. For example, Arık and Topçu [15] provide a meta-synthesis on the implementation of the engineering design process into K-12 science classrooms and present common practices among 46 different articles. The language used to describe the research projects cited in the paper provides credible evidence that studies thus far focus on working with physical models to implement the engineering design process. In undergraduate engineering education, students frequently encounter the application of engineering design thinking in capstone courses as a culminating experience. However, these experiences frequently involve physical design artifacts. This is not surprising given that the literature is replete with research findings like that of Lemons et al. [16] that extol the benefits of using the construction of physical models in teaching and learning of the engineering design process in college courses. Their study investigates whether model building activities contribute to a better understanding of the engineering design process and find positive results in this regard. However, again, the context of this research focuses only on physical design problems and there is a growing need for engineers to solve problems situated in more conceptual contexts with no physical artifacts. Today's engineers must learn how to deal with complex, ambiguous engineering problems—particularly problems situated in large data sets. Further, engineers must develop a tolerance of ambiguity to effectively work in such environments.

Tolerance of Ambiguity

The concept of tolerance of ambiguity (TA) was introduced by Frenkel-Brunswick [17] and during the several decades following, the concept and its measurement have evolved considerably. Frenkel-Brunswick [17] defined TA as an "emotional and perceptual personality variable". Her original psychological view of TA is like that of English and English [18, p. 24] who define ambiguity tolerance as a "willingness to accept a state of affairs capable of alternate interpretations, or of alternate outcomes: e.g., feeling comfortable (or at least not feeling uncomfortable) when faced by a complex social issue in which opposed principles are intermingled." Budner [8, p. 29], whose TA instrument is one of the most often used in research, defined tolerance of ambiguity as "the tendency to perceive ambiguous situations as desirable" and intolerance of ambiguity as "the tendency to perceive (i.e. interpret) ambiguous situations as sources of threat." McLain [19, p. 184] defined TA as "a range, from rejection to attraction, of reactions to stimuli perceived as unfamiliar, complex, dynamically uncertain or subject to multiple conflicting interpretations." TA has further been defined as "the way an individual (or group) perceives and processes information about ambiguous situations or stimuli when confronted by an array of unfamiliar, complex or incongruent clues" [20, p. 179]. MacDonald [9,

p. 791], whose modified scale we will use, states “that persons having high tolerance of ambiguity (a) seek out ambiguity, (b) enjoy ambiguity, and (c) excel in the performance of ambiguous tasks.” It is this latter definition that is used for this research as it describes a skill or mindset that today’s engineering graduates must possess in order to solve the problems they will increasingly face and must be prepared to solve—problems that are complex, fraught with uncertainty, and given to conflicting interpretations by varying components.

“Wicked Problems” Introduce Ambiguity

To better situate the project in the literature and to more explicitly define the nature of suitable problems for our research intervention, wicked problems—as defined in the literature—will be used.

Wicked problems, as described by Farrell and Hooker [25], can be characterized by ten features. (1) Wicked problems have no one way of being defined; the same problem can be framed and contextualized in many ways. (2) Wicked problems have no stopping rule, as there is always the possibility of finding a better option or improvements for a particular solution given more resources. (3) Solutions to wicked problems are not right or wrong, but rather are characterized as some level of good or bad depending on individual values and goals. (4) There is no way to definitively test that a wicked problem has been solved. (5) Wicked problems cannot be feasibly solved through trial and error. Each attempted solution is costly and essentially irreversible. (6) There will be numerous potential solutions devised and many more that will not have been thought of. Judgment must be used to decide if more solutions should be sought, and which solutions should be pursued and implemented. (7) A wicked problem will always have a key element that makes it essentially unique. (8) Every wicked problem stems from another problem. Eliminating one problem could be a part of eliminating the larger problem at hand, and the solution to one problem may cause a new problem to occur. (9) The reasons behind wicked problems can be explained in more than one way, and the chosen explanation will direct how the problem is resolved. (10) Those working to address a wicked problem are liable for the consequences that result from their actions.

These characteristics of wicked problems align well with our intended purpose of better preparing engineering students to deal with the uncertainty, complexity, and ambiguity of the real-world problems they will encounter in engineering practice.

Our Intervention

Our intervention involves the introduction of group projects into an introductory Probability and Statistics for Engineers course that requires students to solve problems fraught with ambiguity. Our hypothesis is that facilitating students’ gaining positive experiences dealing with wicked problems will increase their tolerance for ambiguity. This is a core industrial engineering course that is conceptual in nature. Further, many contemporary problems that industrial engineers are being asked to solve in industry practice involve analysis of large, complex data sets. To this end, all students were given a large data set that is realistic, anonymized data about undergraduate engineering students at USF over a 5-year period. USF awards approximately 8700 bachelor's degrees annually with a total undergraduate enrollment of approximately 37,000 students. Variables in the dataset included demographic data, student major, student matriculation date, student graduation date, and course-level data, among other data over a five-year academic period. Table 1 describes the group project given to the students.

Student teams were given four assignment options to choose from for their projects. Each of the four questions shown in Table 1 represents a different assignment option; each team had to choose one question to answer for their project. The characteristics of these problem options have a lot in common with the aforementioned characteristics of wicked problems. Among the common features are: 1) each problem can be framed and contextualized in multiple ways (e.g., "critical course" may be defined in several ways); 2) there is no optimal solution or predetermined stopping point for development of a solution; 3) there is no definitive right or wrong solution to any of the questions, though some solutions may be better or worse than others (e.g., some statistical approaches to solving the problem may be more appropriate than others); and 4) there are many potential solutions and no way to determine that the problem has been solved. Though specific to probability and statistics, our general pedagogical approach could be applied to any course to which wicked problems could be assigned.

Scaffolding

We anticipated that transitioning students from traditional textbook problems to "wicked problems" would require the provision of additional support. To facilitate students' growth in their ability to effectively deal with "wicked problems", we will employ a scaffolding strategy. Scaffolding is closely associated with Vygotsky's sociocultural theory of cognitive development. A central concept of Vygotsky's theory is the zone of proximal development. Vygotsky defines the zone of proximal development as follows:

"the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem-solving under adult guidance, or in collaboration with more capable peers" [17, p. 86].

Scaffolding describes the support or guidance provided as the learner engages in a task that cannot currently be completed independently.

Three types of scaffolding strategies were considered: cognitive, metacognitive, and affective. Cognitive scaffolding is employed to assist students as they systematically seek to answer and solve the "wicked problem" with which they are presented (e.g., providing specific, expert help regarding how to dissect the large problem into smaller sub-problems such as identifying suitable metrics, classifying the types of relevant variables available in the data set, and identifying applicable statistical techniques). Metacognitive scaffolding is used to help students think through how the material introduced in the class is related and may possibly be used to address aspects of the "wicked problem" (e.g., facilitating students understanding how the individual concepts of probability theory, random variables, statistical distributions, and inferential techniques are connected and can be applied to solve their specific problem). Affective scaffolding is used to provide assurance to students that the uncomfortable uncertainty they may experience during the process of addressing a “wicked problem” is common and to be expected (e.g., providing stories of other engineers’ experiences dealing with wicked problems). Each form of scaffolding is briefly described below:

Cognitive Scaffolding

This form includes providing descriptive structures as well as simplifying a task by giving the solutions to those activities they are not yet able to perform on their own [18].

To support growth in tolerance for ambiguity a group project was introduced to the course. The project was accompanied by a rubric aligned with the phases of the engineering design process to support cognitive scaffolding (See Table 1). The rubric guides students step by step through each phase of the engineering design process as applied to the assignment. In particular, guiding questions support students’ thinking about the right things and performing the right actions to produce specific deliverables.

Table 1 - Student Team Assignment for Probability and Statistics

<table>
<tr><td colspan="3">In this assignment, you will work in groups to address one of the questions below using the data that has been provided. As part of your response, you must use at least one descriptive and one inferential statistical technique; and offer 3 recommendations to the College of Engineering Administrators about how to improve student outcomes.</td></tr>
<tr><td>Assignment Options:</td><td colspan="2">● What is the most critical course for your major?
● Is Calculus III necessary for all engineers and computer scientists?
● Is it necessary to focus on transfer student success in higher education?
● What, if any, groups seem disadvantaged in your college?</td></tr>
<tr><td>Design Phase</td><td>Questions to Consider</td><td>Deliverable</td></tr>
<tr><td>Define the problem</td><td>How should the problem be scoped? What metric(s) will be used?</td><td>Brief report describing the problem you have selected and your team’s approach to addressing it.</td></tr>
<tr><td>Identify the constraints</td><td>What data are relevant among the data that have been provided? How much time do we have to complete the assignment? What techniques do we know how to use or can learn to use?</td><td>Concept map relating concepts covered in class and the techniques you will employ in addressing the problem your team selected.</td></tr>
<tr><td>Brainstorm possible solutions</td><td>What statistical techniques are appropriate given our selected problem?
What data can possibly be used? What metrics can possibly be used?</td><td>Updated report</td></tr>
</table>

Select the preferred option	What data will be used? What metrics will be used? Which analysis techniques will be used?	Descriptive statistics describing your sample data; interpretation of results.
Build a prototype	Were you able to conduct the analysis? Do the results seem reasonable? Were the results what you expected? What are your recommendations?	Inferential statistic(s) that address the problem; interpretation of results.
Test a prototype	What feedback did you receive from the preliminary presentation of your results?	Present design review in class and to relevant stakeholders; feedback from reviewers.
Revise and iterate	What changes will you make based on the feedback received?	
Communicate results	How will you communicate the results of your analysis?	Final report.

Metacognitive Scaffolding

The idea of this type is to assist the students by making they think about what they really think. In summary, to help them develop their ability to manage their own learning [18]. For this assignment, metacognitive scaffolding was provided in the form of a concept mapping exercise.

Concept mapping exercises and writing to learn (WTL) exercises will support metacognitive scaffolding. Students will be asked to produce concept maps that connect discrete topics introduced in class to help solidify the conceptual connectedness of the topics. This understanding will reinforce the ability to correctly apply the concepts to solve the novel "wicked problem" that is the basis of the group project.

Deepening the students' conceptual understanding of the course material is also at the heart of the writing to learn exercise, which emphasizes understanding the meaning and repercussions of the quantitative outcomes produced by the statistical procedures used by the students to solve problems.

Affective Scaffolding

The third and final part of the scaffolding approach can be used to develop and sustain students' interest in achieving a goal. Also, a reward is provided, helping with their frustration with the challenges previously found [18].

To support affective scaffolding, guest speakers will be invited to speak to students about solving "wicked problems" they have encountered in engineering practice and what it "looks like" and "feels like" to solve such problems as well as common challenges one can expect to encounter along the way.

Conclusions

Our research is a work in progress. We have completed an exploratory factor analysis of our assessment instrument and will soon conduct a confirmatory factor analysis. Notwithstanding the current status of our work, we believe that students should be exposed to problems more complex than the traditional engineering textbook problem to facilitate the development of the complex problem solving skills they will need to address the real-world problems they will encounter in contemporary engineering practice. “Wicked problems” offer the characteristics of such problems. However, care must be taken to provide the necessary scaffolding to support students as these more complex problems will likely produce a different zone of proximal development for students. This paper introduces three types of scaffolding to consider as more complex problems are introduced in an engineering course: cognitive, metacognitive, and affective. While the purpose of this paper was just to introduce the types of scaffolding considered , we hope to report on the efficacy of the intervention in subsequent work. We look forward to reporting the results of our research as we continue to assess its efficacy.

References

[1] Statistics, U.S. Bureau of Labor Statistics. *Occupational Outlook Handbook: Fastest Growing Occupations*. 2019 [cited 2020 November 5]; Available from: https://www.bls.gov/ooh/fastest-growing.htm.
[2] National Academy of Engineering. *NAE Grand Challenges for Engineering*. [cited 2020 November 5]; Available from: http://www.engineeringchallenges.org/challenges.aspx.
[3] Kolko, J., *Wicked Problems: Problems Worth Solving: A Handbook & A Call to Action*. 2012, Austin, TX: Austin Center for Design.
[4] Atman, C.J., O. Eris, J. McDonnell, M. E. Cardella, and J. L. Borgford-Parnell, "Engineering Design Education: Research, Practice, and Examples that Link the Two," in *Cambridge Handbook of Engineering Education Research*, A. Johri and B.M. Olds, Editors. 2014, Cambridge University Press: New York, NY.
[5] Jonassen, D.H., "Engineers as Problem Solvers," in *Cambridge Handbook of Engineering Education Research*, A. Johri and B.M. Olds, Editors. 2014, Cambridge University Press: New York, NY.
[6] Stevens, R., A. Johri, and K. O'Connor, "Professional Engineering Work," in *Cambridge Handbook of Engineering Education Research*, A. Johri and B.M. Olds, Editors. 2014, Cambridge University Press: New York, NY.
[7] Wendell, K.B. and J.L. Kolodner, "Learning Disciplinary Ideas and Practices Through Engineering Design," in *Cambridge Handbook of Engineering Education Research*, A. Johri and B.M. Olds, Editors. 2014, Cambridge University Press: New York, NY.
[8] Arik, M. and M.S. Topcu, "Implementation of Engineering Design Process in the K-12 Science Classrooms: Trends and Issues," *Research in Science Education*, 52, 2020.
[9] Lemons, G., A. Carberry, C. Swan, L. Jarvin and C. Rogers, "The benefits of model building in teaching engineering design," *Design Studies*, 31(3), p. 288-309, 2010.
[10] Frenkelbrunswik, E., "Intolerance of Ambiguity as an Emotional and Perceptual Personality Variable," *Journal of Personality*, 18(1): p. 108-143, 1949.
[11] English, H.B. and A.C. English, *A Comprehensive Dictionary of Psychological and Psychoanalytical Terms*. 1958, New York: McKay.
[12] Budner, S., "Intolerance of Ambiguity as a Personality Variable," *Journal of Personality*,. 30(1): p. 29-50, 1962.
[13] McLain, D.L., "The MSTAT-I - A New Measure of an Individual's Tolerance for Ambiguity," *Educational and Psychological Measurement*, 53(1): p. 183-189, 1993.
[14] Furnham, A. and T. Ribchester, "Tolerance of ambiguity: A review of the concept, its measurement and applications*," Current Psychology*, 14(3): p. 179-199, 1995.
[15] MacDonald, A.P., "Revised Scale for Ambiguity Tolerance - Reliability and Validity," *Psychological Reports*, 26(3), 1970.
[16] Farrell, R. and C. Hooker, "Design, science and wicked problems," *Design Studies*, 34(6): p. 681-705. 2013.
[17] Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

[18] Lönngren, J., Adawi, T., & Svanström, M. (2019). Scaffolding strategies in a rubric-based intervention to promote engineering students' ability to address wicked problems. *European Journal of Engineering Education*, *44*(1-2), 196-221.