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WIP: A Pedagogical Intervention Leveraging Engineering Design Thinking to Foster a Tolerance for Ambiguity

Julia Machele Brisbane

Julia Brisbane is a Ph.D. student in the Engineering Education Department at Virginia Tech.

Jeremi London

Associate Professor of Engineering Education at Virginia Tech Chair of ASEE's CDEI during the Year of Impact on Racial Equity

Kingsley A. Reeves (Associate Professor)

Kingsley Reeves is an Associate Professor at the University of South Florida in the Industrial and Management Systems Engineering Department. His current research interests focus on the lean six sigma philosophy and applications of traditional industrial engineering methods to solve problems in the education service sector. He is also active in engineering education research with a focus on the formation of ethical engineers. Kingsley is also a current RIEF mentee.

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Abstract

Tolerance for Ambiguity (TA) is the ability to seek out, enjoy, and excel in ambiguous tasks. This is a skill or mindset that today's engineering graduates must possess in order to address the problems they must be prepared to solve—problems that are complex, fraught with uncertainty, and given to conflicting interpretations by varying constituents. It can be argued that students with a higher tolerance for ambiguity will be better suited to proactively engage in, enjoy, and excel in finding solutions to the contemporary problems faced by 21st-century engineers. In contrast, students with a lower tolerance for ambiguity may be unmotivated in the modern engineering work environment and struggle to perform well. Given this reality, pedagogical innovations shown to increase students' tolerance for ambiguity have the potential to better prepare the future engineering workforce. However, there are few examples of how to do this in engineering and/or how to measure the effectiveness of our efforts. This paper briefly describes the development of a pedagogical intervention designed to increase sophomore engineering students' tolerance for ambiguity. The context of this study is an undergraduate engineering statistics course offered by the Industrial Engineering department at a large university located in the southeast. Students will be given a large hypothetical data set that mimics real data the undergraduate student experience (e.g., GPAs, course completion rates), and asked to use the engineering design process to identify and solve a data-rich problem using statistical techniques they have learned in the course. Two well-established measures of TA were adapted for this study; the result of the face validity check will also be discussed. This paper closes with insights on how these measures will be used to evaluate the impact of the intervention. The findings of this study will not only advance our understanding of pedagogical strategies for fostering the development of this 21st century skill, but also give us meaningful ways to measure the effectiveness of our efforts.

Overview

The design process is an integral part of undergraduate engineering education. This is due to the increased demand for an engineering workforce that has strong analytical skills that can solve data-driven problems. The National Academy of Engineering has outlined fourteen grand challenges in engineering that require interdisciplinary expertise and complex solutions [1]. What unifies these challenges is that they are all data-driven and requires design thinking. Design thinking is imperative in solving 21st century engineering problems, regardless of the type of engineer involved [2]–[4]. Thus, it is important that students are engaged in the engineering design process, in hopes that they will have a smooth transition from school to the workforce[5]. The design process provides a framework for scoping problems considering constraints, brainstorming possible solutions, selecting among the best options, prototyping solutions, iteratively testing, and effectively communicating outcomes, which will all be helpful to undergraduate engineering students when entering the workforce [2], [6].

While the design process is heavily emphasized throughout undergraduate engineering education via first-year engineering courses, project-based courses, and capstone, current approaches to teaching the design process are largely centered around developing a physical artifact [7], [8]. However, a lot of problems that need to be solved by today's graduating engineers are data-driven [9] – and with data-driven problems comes ambiguity. Students will need to understand the contextual factors surrounding data sets, deal with incomplete information, and deal with problems that have more than one right answer. They will need to understand how to choose among options for analytical techniques and appropriately apply them. It is also critical that they develop the skills needed to interpret results, outline the practical implications of those results, and effectively communicate their findings to decision-makers. While there is a growing body of work incorporating ambiguity into teaching engineers how to solve data-driven problems, there is still room for improvement [10]. However, design thinking has the potential to bridge this gap. Rarely is the engineering design process thought of as a mechanism that can be leveraged to deal with the uncertainty embedded in solving data-driven problems, but this study aims to explore its potential to do so.

There is a growing body of knowledge on the importance of tolerance for ambiguity in engineering education. Toh and Miller found that tolerance for ambiguity was important for engineering students to have for creative concept generation in engineering design [11]. Mohammed and colleagues found that a higher tolerance for ambiguity increased the self-efficacy, satisfaction, and conflict resolution of students working on an engineering design project [12]. Based on the existing literature, it can be argued that students with a higher tolerance of ambiguity will be better suited to engage and solve contemporary problems faced by 21st-century engineers due to the skills they may gain from this ability. In contrast, students with a lower tolerance of ambiguity may be unmotivated in an engineering work environment and struggle to perform well. Given this reality, pedagogical innovations, shown to increase student tolerance of ambiguity, have the potential to better prepare the future engineering workforce.

The purpose of the project overall is to understand how engineering design can be leveraged to solve ambiguous, data-driven engineering problems in an undergraduate probability and statistics course. More specifically we are investigating two aims: 1) reimagine the role design thinking can play when engineers wrestle with the ambiguity embedded in big data problems; and 2) reimagine the way undergraduate engineering students learn introductory probability and statistics concepts. As part of the redesign phase of the study, baseline data needs to be collected on students' ambiguity tolerance. Although existing instruments for measuring tolerance for ambiguity in other contexts exist, there is a need to perform a face validity check and finalize the survey instruments before administering them to students. Thus, the focus of this paper is to present the results of the face validity check t and outline next steps for the project overall.

Tolerance of Ambiguity

The concept of tolerance of ambiguity (TA) was introduced by Frenkel-Brunswick [6] and during the several decades following the concept and its measurement have evolved considerably. Frenkel-Brunswick [13] defined TA as an "emotional and perceptual personality variable" [pg. 791]. TA has been defined many times, but MacDonald [14], whose modified scale was used in this study, states:

"[P]ersons having high tolerance of ambiguity (a) seek out ambiguity, (b) enjoy ambiguity, and (c) excel in the performance of ambiguous tasks."

It is this definition that we will use for our research that describes what present-day engineering graduates must possess to address the problems they will face in the engineering workforce—problems that are complex, filled with uncertainty, and have conflicting interpretations.

One of the best known and widely-used scales to measure TA was developed 30 years ago by Budner [15] who devised a 16-item scale. Rydell and Rosen [16] and Rydell [17] reported on the development and validation of another scale that consisted of 16 true-false items that were constructed on an "a-priori basis" [9] with relatively limited validation. MacDonald [14] added four items to the Rydell-Rosen scale to improve its validity and provided evidence for the instrument's construct validity by an increased split-half reliability coefficient (.64 to .86) [14]. The wording of items in the Budner scale has been criticized for their failure to represent the appropriate stimulus, or even suggest ambiguity at all [18]. The items are also argued to be in response to specific situations, which may elicit misleading reactions. However, Herman notes that tolerance for ambiguity may function differently depending on the setting [19]. Additionally, the research team perceived that the nature of the items in the Budner scale may be less susceptible to modification based on our pedagogical intervention in the probability and statistics course. We have, therefore, decided to use the widely-used Budner scale along with the MacDonald scale in our proposed work, but only after performing a face validity check with engineering students that share characteristics as those that will participate in the study.

Validity is an ongoing process in which the developers and future collaborators are further enhancing the quality of a survey instrument by collecting evidence so the instrument can be used in various contexts [20]. While these instruments have been validated in previous research a face validity check needed to be performed to ensure that the items are accurately interpreted before administering to students in a probability and statistics course. While there have been surveys testing the ambiguity, there has not been a face validity check of these surveys. Face validity is important as it assesses if a survey measures what it is intended to measure [21], [22]. By doing the face validity check, we will be able to deliver the survey to a wider group of students and measure changes in student tolerance for ambiguity using the two scales.

Methods

Face validity is a validity construct that is used to evaluate how survey items appear to the population being studied [23]. Oftentimes, the content, criterion and construct validity are used to establish the validity of a survey, but while they are important in instrument development, assessing the perspective of the participant is important to know if the survey item measures what is intended to be measured [21], [24]. Dimensions used to measure face validity include accuracy, likability, item relevance, perspective, and rate of accurate completion [21]. A face validity check is important when re-using existing instruments in a new context because the context in which the survey is taken can affect the face validity of the instrument [22]. The absence of face validity in these situations can result in the participant feeling dissatisfied, which can lead to the participant not being able to answer the items properly, thus it is important that a face validity check was conducted for this study [22].

In order to conduct the face validity check of the survey, a focus group with five students was conducted. Face-to-face interviews and focus groups are commonly used when assessing face validity, as they can be used to assess the participants' understanding of the survey instrument [24]–[26]. Participants were identified as students who previously took the probability and statistics course taught by one of the PIs for this project. Additionally, the course is offered by a faculty member in the Industrial Engineering Department, in which this same PI resides. As shown in Table 1, the participants came from a diverse set of backgrounds, with most being bilingual. This is important to note since the setting surrounding the study is a large southeastern university, where a significant portion of the students are bilingual. A majority of the focus group participants were racial and/or ethnic minorities and all but one identified as female. Approximately 22 percent of the college of engineering at this university identify as either Black or Hispanic, along with 23 percent of the college of engineering identifying as female. It was imperative that those who are typically marginalized in engineering were able to voice their perspectives of the survey instrument.

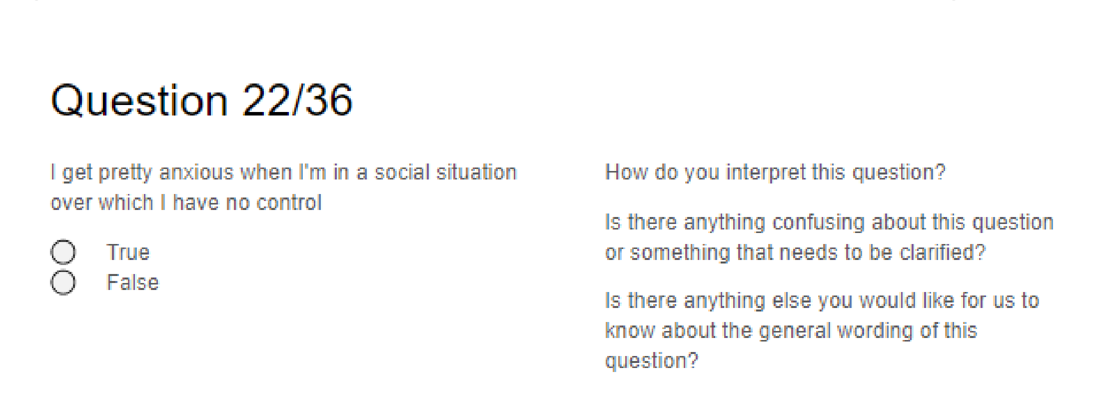
Table 1: Demographics of the Focus Group Participants

Major	**Bilingual?**	**Race**	**Year**	**Gender**
Industrial Engineering	Bilingual	Latino	Junior	Male
Industrial Engineering	Non-bilingual	White	Junior	Female
Industrial Engineering	Not Specified	Black-Haitian	Junior	Female
Industrial engineering	Bilingual	Latina	Junior	Female

Industrial Engineering	Bilingual	Hispanic	Senior	Female

In the focus group, a slide was shown with each survey item. Participants were asked three questions for each survey item: 1) How do you interpret this question? 2) Is there anything confusing about this question or something that needs to be clarified? And 3) Is there anything else you would like for us to know about the general wording of this question? This focus group lasted approximately one hour.

Figure 1: Sample slide with a survey item and questions for the focus group



The focus group was conducted during a one-hour virtual session and recorded on Zoom. The graduate student working on the project took notes while each participant discussed and suggested changes for each question. Afterwards, the graduate student listened to the recording while taking a first pass at editing the questions in light of the participants'. The recording was used to make suggestions to the survey questions that focus group participants thought needed to be revised. One of the PIs for the project made a final revision of the questions and placed them in a new order. The finalized survey was administered to students taking the probability and statistics course via Qualtrics.

Results of Face Validity Check

Table 2 below shows the results of the face validity check. In short, twenty-three (23) out of thirty-six (36) questions on the combined survey were revised. Examples of changes to the questions entailed slight wording changes. As noted during the focus group, the majority of the participants were bilingual and noted that some of the sentences were hard for them to understand due to learning English as a second language. Each question that participants noted as unclear were revised for clarity using their input. Examples of changes to questions include using shorter and simpler language, using words that are more commonly used in place of less common words, and avoiding complex sentences. Additionally, the order in which the questions appeared was also altered based on the faculty members' perceptions of which topics seemed more closely related. Initially, the Budner scale [15] was listed before the MacDonald scale [14]. The MacDonald scale had true and false as answer choices, which went over much easier for the participants which resulted in the MacDonald scale being listed first. All revised questions are emphasized in bold within the table.

Table 2: Original and Revised Items in Tolerance for Ambiguity Scales

Original Survey Item (A: MacDonald; B: Budner)		Revised Question	
19	There's a right way and a wrong way to do almost everything [A]	1	There's a right way and a wrong way to do almost everything
22	I get pretty anxious when I'm in a social situation over which I have no control [A]	2	**I feel anxious in social situations I have no control over**
17	A problem has little attraction for me if I don't think it has a solution [A]	3	**A problem is uninteresting to me if I don't think it has a solution**
18	I am just a little uncomfortable with people unless I feel that I can understand their behavior [A]	4	**I am slightly uncomfortable with people unless I can understand their behavior**
20	I would rather bet 1 to 6 on a long shot than 3 to 1 on a probable winner [A]	5	I would rather bet 1 to 6 on a long shot than 3 to 1 on a probable winner
21	The way to understand complex problems is to be concerned with their larger aspects instead of breaking them into smaller pieces [A]	6	**The way to understand complex problems is by going over the larger aspects instead of breaking them into smaller pieces**
23	Practically every problem has a solution [A]	7	Practically every problem has a solution
24	It bothers me when I am unable to follow another person's train of thought [A]	8	It bothers me when I am unable to follow another person's train of thought
25	I have always felt that there is a clear difference between right and wrong [A]	9	**There is a clear difference between right and wrong**
26	It bothers me when I don't know how other people react to me [A]	10	It bothers me when I don't know how other people react to me
27	Nothing gets accomplished in this world unless you stick to some basic rules [A]	11	Nothing gets accomplished in this world unless you stick to some basic rules
28	If I were a doctor, I would prefer the uncertainties of a psychiatrist to the clear and definite work of someone like a surgeon or X-ray specialist [A]	12	**I would prefer the uncertainties of an English assignment over the clear and definite work of a Math exam**
29	Vague and impressionistic pictures really have little appeal for me [A]	13	**Vague artistic pictures have little appeal for me**
30	If I were a scientist, it would bother me that my work would never be completed (because science will always make new discoveries) [A]	14	**As an engineer, it would bother me that my work would never be completed**
31	Before an examination, I feel much less anxious if	15	**I feel less anxious if I know how many**

	I know how many questions there will be [A]		**questions there will be before an exam**
32	The best part of working a jigsaw puzzle is putting in that last piece [A]	16	The best part of working a jigsaw puzzle is putting in that last piece
33	Sometimes I rather enjoy going against the rules and doing things I'm not supposed to do [A]	17	**Sometimes I enjoy going against the rules and doing things I'm not supposed to do**
34	I don't like to work on a problem unless there is a possibility of coming out with a clear-cut and unambiguous answer [A]	18	**I don't like to work on a problem unless there is a possibility of coming out with a clear-cut, unambiguous answer**
35	I like to fool around with new ideas, even if they turn out later to be a total waste of time [A]	19	I like to fool around with new ideas, even if they turn out later to be a total waste of time
36	Perfect balance is the essence of all good composition [A]	20	**The essence of any good creation is balance**
2	I would like to live in a foreign country for awhile [B]	21	**I would like to live in a foreign country for a while**
3	There is no such thing as a problem that can't be solved [B]	22	There is no such thing as a problem that can't be solved
4	People who fit their lives to a schedule probably miss most of the joy of living [B]	23	**The joy of living comes from not fitting your life to a schedule**
1	An expert who doesn't come up with a definite answer probably doesn't know too much [B]	24	**An expert who doesn't come up with a definite answer probably doesn't know much about the topic they are speaking about.**
6	It is more fun to tackle a complicated problem than to solve a simple one [B]	25	It is more fun to tackle a complicated problem than to solve a simple one
5	A good job is one where what is to be done and how it is to be done are always clear [B]	26	**A good job makes clear what needs to be done and how it is to be done**
7	In the long run, it is possible to get more done by tackling small, simple problems rather than large and complicated ones [B]	27	**In the long run, more can get done by tackling small, simple problems than tackling large, complicated ones.**
8	Often the most interesting and stimulating people are those who don't mind being different and original [B]	28	Often the most interesting and stimulating people are those who don't mind being different and original
9	What we are used to is always preferable to what is unfamiliar [B]	29	**It is always preferable to do what I am used to over something unfamiliar**
10	People who insist upon a yes or no answer just don't know how complicated things really are [B]	30	**People who insist upon a "yes" or "no" answer just don't know how complicated things really are**
11	A person who leads a life in which few surprises or unexpected happenings arise really has a lot to be grateful for [B]	31	**A person who leads a life with few surprises has a lot to be grateful for**

12	Many of our most important decisions are based on insufficient information [B]	32	**Most of our important decisions are based on insufficient information**
13	I like parties where I know most of the people more than the ones where all or most of the people are complete strangers [B]	33	**I like parties where there are more people I know than strangers**
14	Teachers who hand out vague assignments give a chance for one to show initiative and originality [B]	34	**Teachers who hand out vague assignments give students a chance to show initiative and originality**
15	The sooner we all acquire similar values and ideals the better [B]	35	The sooner we all acquire similar values and ideals the better
16	A good teacher is one who makes you wonder about your way of looking at things [B]	36	A good teacher is one who makes you wonder about your way of looking at things

Next Steps

The revised survey items were put into Qualtrics, and baseline survey data was collected from students enrolled in one Fall 2021 section of the introductory probability and statistics course that will be revamped over the next year. In light of the changes made to survey items, the research team will pursue other measures of validity in order to further validate the instrument for our usage. A quasi-experimental study will be conducted to examine if an intervention will have an impact on the students' tolerance for ambiguity in the class. The survey responses will be used as a point of comparison once more data is collected next year, after the course is redesigned. Changes in student tolerance for ambiguity will be analyzed using a pre-post analysis. This survey will be administered to the students in the PI's section of probability and statistics twice: during the first and last week of class. Students enrolled in another section of the same course (not taught by the PI) will also be invited to take the survey and will serve as a control group. For students enrolled in the PI's section of the course, we will perform a paired t-test to determine if there is a statistically significant difference in students' responses to survey items given at the beginning and the end of the semester. This will determine if the intervention had an impact on the class. We will also perform an ANOVA to determine if there is a statistically significant difference in responses to the survey based on whether they are enrolled in the PI's section or not. We will make sense of both sets of results in light of the aim to determine the extent to which tolerance for ambiguity can be influenced by introducing the design process in an introductory probability and statistics course to help deal with uncertainty.

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