Comparing Engineering Students' and Professionals' Conceptions of Ambiguity

Elliot P. Douglas
Department of Environmental Enginering Sciences
University of Florida
Gainesville, FL, USA
edouglas@ufl.edu

David J. Therriault
School of Human Development and Organizational Studies
University of Florida
Gainesville, FL, USA
therriault@coe.ufl.edu

Marah B. Berry
Department of Environmental Enginering Sciences
University of Florida
Gainesville, FL, USA
m.berry@ufl.edu

Jeremy A. M. Waisome
Department of Engineering Education
University of Florida
Gainesville, FL, USA
jwaisome@eng.ufl.edu

***Abstract*— Engineers are frequently confronted with complex, unique, and challenging problems. Many of our most pressing engineering problems contain ambiguous elements, and a core activity of engineering is being able to solve these complex problems effectively. While engineering problems are often described as ambiguous, ambiguity has not been clearly defined in the literature in the context of engineering problem solving. This work-in-progress paper describes our initial results to understand how ambiguity is experienced during engineering problem solving. We interviewed both engineering students and engineering professionals about ambiguous problems they have encountered. We found that both groups identified technical ambiguity as the core element of engineering problem solving. They also described differences between classroom and workplace problems, with students describing classroom problems as "purposefully" ambiguous. Students had strong negative emotional reactions to ambiguity, in contrast to professionals who seemed to accept ambiguity as a common element in engineering problems. Our initial findings suggest that changes to engineering education practice that allow students to become comfortable with ambiguity would better prepare them for the ambiguous problems they will face in the workplace.**

Keywords—problem solving, ambiguity, qualitative

I. Introduction

The engineering problems of the 21st century, such as climate change, global pollution, and water security, are complex and have no easy solutions. The engineering students we are educating today must become comfortable with complexity and ambiguity to prepare them for the problems they will face in their careers. This work-in-progress paper describes our initial work to better understand the role of ambiguity in engineering problem solving.

Within the existing literature, many engineering problems are dichotomously characterized as either well-structured (unambiguous) or ill-structured (ambiguous). Ambiguity, if it is mentioned at all in the problem classification, is only identified as a structural element. Ambiguity has not yet been adequately operationalized in the engineering problem solving literature or the problem solving literature more generally. As a result there is little research specifying different types of ambiguity or how problem solvers may experience ambiguity differently within the same problem. Without a better understanding of ambiguity in problem solving, it is difficult to develop educational approaches that will teach students how to successfully navigate ambiguous problems.

Most commonly, engineering problems are classified as ill-structured or well-structured. Ill-structured problems are characterized as more complex and less determinate, not providing all information necessary to solve the problem, and not providing an established set of choice possibilities [1-3]. Ambiguity, if it is mentioned, is generally not defined in the context of problem solving. Two exceptions are papers by Doyle and Carter [4] and by Schrader, Riggs, and Smith [5]. Doyle and Carter discuss problem solving in the context of evaluation, in which problems are solved "under conditions of ambiguity and risk" (p. 131). According to them, "*Ambiguity* refers to the extent to which a precise and predictable formula for generating a product can be defined. *Risk* refers to the stringency of the evaluation criteria and the likelihood that these criteria can be met on a given occasion" (p. 131, italics in original). Schrader, et al., contrast ambiguity and uncertainty. They argue that uncertainty is characterized by a lack of information and this is distinct from ambiguity (characterized as a lack of clarity of relationships). Uncertainty is reduced by information gathering and integration, whereas ambiguity is reduced by model building, problem framing, evaluation, and testing [5].

To expand our understanding of what ambiguity is in the context of engineering problem solving, this work in progress paper poses the research question, what are the qualitatively different ways that novice and expert engineers experience ambiguity? We present the initial set of themes derived from interviews with both engineering students and practicing engineers.

II. Methodology

We conducted interviews with 14 engineering students and 16 engineering professionals. Students were recruited through emails and visits to classes. Students needed to be 3rd year or higher undergraduate students in civil engineering to be eligible. Professionals were recruited through the alumni list of the civil engineering department, personal contacts, and snowball sampling. Professionals needed to be working in a civil

Funding was provided through U.S. National Science Foundation grant EEC-1824610.

engineering position and have been working at least eight years since their highest degree in order to ensure sufficient experience with problem solving in the workplace. Tables I and II provide demographic information for the participants. Participants were provided with gift cards to local stores as incentives for participation. Names given in this paper are pseudonyms. Names are followed by either the letter P or S in parentheses to indicate whether that person was a professional engineer (P) or engineering student (S). All procedures were approved by the university's Institutional Review Board.

TABLE I. STUDENT DEMOGRAPHICS

Race	12 White, 2 Black
Ethnicity	10 Non-Hispanic, 4 Hispanic
Gender	6 male, 8 female
Age	Range from 20 to 23

TABLE II. PROFESSIONAL ENGINEER DEMOGRAPHICS

Race	7 White, 6 Black, 2 Asian, 1 Native American
Ethnicity	12 Non-Hispanic, 4 Hispanic
Gender	9 male, 7 female
Age	Range from 32 to 60
Highest degree	7 Bachelors, 7 Masters, 1 MBA, 1 PhD
Years since highest degree	Range from 8 to 30

We conducted interviews using artifact elicitation [6], in which an artifact (in this case, ambiguous problems) are used as concrete examples to help begin a conversation about a concept (in this case, ambiguity). Before the interviews we asked the participants to send us problems they had encountered that they felt were ambiguous. We deliberately did not define "ambiguous" for them so as not to influence what they selected. During the interviews we asked them to explain why these problems were ambiguous, which then led into a further discussion of general aspects of ambiguity in engineering problem solving.

The first author was the primary analyst. He used inductive coding techniques [7] along with constant comparison [8] to identify how each participant talked about their experiences with ambiguity. Segments of the transcripts were labeled with initial codes, which were then grouped into focused codes and themes. After each round of coding the other authors reviewed the coding and suggested modifications. This paper describes an initial set of themes, which are still being refined.

III. RESULTS

Our initial set of themes of students' and professionals' experiences with ambiguity are: technical ambiguity; classroom vs. workplace problems; and emotional responses to ambiguity. Each of these is described further in the next sections.

A. *Technical Ambiguity*

Both students and professionals recognized the presence of technical ambiguity in engineering problems. Technical ambiguity was most often described as being due to unclear or changing scope, missing information, unknown path to a solution, or multiple possible solutions. For professionals, unclear scope was attributed to clients, while for students it was attributed to instructors. For example, Carlos (P) said that, "I would say that the request would not be well defined enough. Maybe to the owner it sounded well-defined enough but from an engineering perspective, a structural engineering perspective, it was not well-defined." John (S) described a design class in which the instructor gave them an overall problem but not a specific design scope, saying "it's a very unstructured class… now we have to like figure out what to do with it."

Missing information was often cited as a source of ambiguity. Professionals recognized this aspect as a natural element of engineering problems. Robert (P) said that "as a design engineer, we face technical challenges and are oftentimes uncertain how to proceed because all the information may not be there to make a decision. And I quickly learned, or I think I learned, that you don't always know, you're never entirely sure, it's not always completely clear what the right path is." One of the differences between students and professionals was that professionals knew how to find the needed information, while students had to learn how to do that. Beth (S) described learning how to use a design code manual: "They just said, hey, use this document to solve this problem. Not telling us, you know, look in chapter 16, find it from there. We had to know where to look, what information we needed, the little subscripts on subscripts of everything. So it was learning those type of things."

Both groups also described ambiguity stemming from multiple or unknown solution paths. Cindy (S) explained the process for solving a classroom problem as "So it kind of depends on what order you go in. So there's no really right or wrong order to go in. It's just I went chronologically. Some of the other people in the class went with whatever they could find in the book first. So like in the book first, if they found the drainage factor first, that's what they, would plug that into an equation and get a coefficient for that. So it doesn't really make a difference what order you put them in, you'll still get something that works." For her, the ability to solve the problem in multiple ways made it ambiguous. In contrast, both Sam (S) and Tim (S) did not think that having multiple solution paths resulted in ambiguity when those different paths led to the same answer. Ben (P) took this point even further saying that technical problems are never ambiguous: "From an engineering standpoint, there's not too much [ambiguity]. Like there's more than one way to grade a site, there's more than one way to lay out a parking lot, there's more than one way to design your utilities through a site. But it's really not an ambiguous problem to solve from an engineering standpoint." Anne (S) provided an interesting perspective. According to her, "I feel in early [university] education I was taught to always have a single way to approach a problem, that there is only one [way to solve a problem].” She has had to learn through her engineering classes that this is not always the case: “Really, you think there would be a right way, but I’m learning that there is not an exact way.”

B. Classroom vs. Workplace Problems

When comparing the differences between classroom and workplace problems, professionals said that classroom problems were either unambiguous or less ambiguous than workplace problems. Many of the professionals also said that they learned to handle ambiguity in the workplace, either during internships or after they started working. Erica (P) summarized the limitations of her education, saying “And I think the big issue is that sometimes on the engineering side of things they teach us so much black and white that sometimes the gray area doesn’t make sense because all of my teachers are essentially teaching me to think black and white. Every now and then you get a professor that lets you have a little gray area but for the most part it’s black and white. It’s either this or it’s not.”

In contrast, students saw substantial ambiguity in classroom problems (as described in the previous section), but also said that this ambiguity was artificially imposed by the instructor. Anne (S) attributed this “purposeful ambiguity” to instructors wanting to “make it feel more real world about how you’re given a project but nobody’s pretty much holding your hand,” and that “I have to understand that it’s that way because I’m going to see this later and they want me to know about it now so that I can tackle a situation like this later.” However, Heidi (S) did not see a useful purpose in making classroom problems ambiguous, saying “I think in school it’s either a poorly written question or they’re doing it to purposely trip you up because they, for whatever reason, have to make it harder.”

Another difference that students identified between classroom and workplace problems was the importance of those problems. They felt less pressure to get classroom problems correct because there was less at stake; a bad grade only affected themselves, but an error in a workplace problem had broader impact. As stated by Frank (S), “So if I do bad on a homework question I get like a lower grade but if I upset a client…they aren’t going to appreciate that…you don’t want to upset the client because they spent a lot of money on it.”

C. Emotional Responses to Ambiguity

The biggest difference between professionals and students in our dataset was their emotional responses to ambiguity. For the most part professionals did not talk about emotions. They seemed to accept the presence of ambiguity as an expected element of engineering problems. Only Michelle (P) mentioned any strong emotions, saying “Because we all go through it, you know what I mean, we all struggle with, am I supposed to know this? Wait, have I seen this before? Just that self-doubt or facing a new problem and not knowing how to handle it.”

While not all students talked about emotions related to ambiguity, those that did had strong negative emotions. These emotions included fear, anxiety, and lack of motivation. John (S) described it as “when I’m not sure of how to do something, that’s when I really get stressed out. When I don’t think I can complete a task on my own that’s when I get stressed out,” which led to “a lot more procrastination and self-loathing.” Tina (S) felt anxiety over a presentation, saying, “and the fact that we had to present it, I think would've made it a little bit more nerve wracking because you're going to be standing in front of the entire class and you want make sure that you're talking about the right information.” According to John (S), grades associated with ambiguous problems were a significant source of anxiety: “Also it was a Master’s class, so I needed a B+ and I was paying extra for it so I was like, if I have to fail this class and take it again I’m going to be really [upset].”

Some students enjoyed the challenge posed by ambiguous problems and found them motivating. Frank (S) said, “I think it definitely makes you want to pursue it more. Especially if you can overcome it. So even though something’s hard, if you understand even a little bit of it then you want to do more of it.”

IV. Discussion and Conclusions

This paper provides a preliminary comparison of engineering professionals’ and students’ experiences with ambiguity. While there are commonalities between these experiences, it seems that professionals see ambiguity as a natural component of engineering problems, while students see it as an obstacle to be overcome (often artificially imposed). This difference is evident in, for example, Robert’s (P) statement that design engineers “are oftentimes uncertain how to proceed,", contrasted with Heidi (S) saying “I think in school it’s either a poorly written question or they’re doing it to purposely trip you up…” The strong, negative emotions experienced by students also point to ambiguity as an obstacle. Students’ feelings of fear, anxiety, and lack of motivation due to ambiguous problems can prevent them from making the cognitive gains necessary to become effective problem solvers.

Both Anne (S) and Erica (P) (as well as other participants) provided important perspectives on why students struggle with ambiguity. Anne’s (S) first classes in the university taught her that problems are solved using specific algorithms. In some cases, she lost points on her grade when she had the correct answer but had used the wrong procedure. It is not surprising, then, that she struggled in her engineering classes to understand that it would be her decision on what solution path to use. Similarly, Erica (P) said that her university instructors did not teach her how to deal with the “grey areas” in engineering problems. Instead, she (and others, both professionals and students) said that approaches to handling ambiguity were learned in the workplace.

In separate work we have shown that statics textbook problems are solely well-structured and unambiguous [9]. If students are only exposed to well-structured problems in their foundational engineering classes, it is to be expected that they will struggle when they face ambiguous problems later in their education. We encourage instructors at all levels, from foundational courses such as statics and circuits all the way to capstone design, to intentionally include relevant ambiguity when designing problems. Scaffolding instruction around those problems will aid in developing students’ capacity to solve ambiguous problems.

Our future work on this topic will occur along two paths. From a research standpoint, we will refine our analysis and identify different types of ambiguity in engineering problem solving. We will then use those results to construct problems with different types of ambiguity and conduct controlled experiments to understand how students respond to the different types. From an education standpoint, we aim to create guidelines and materials to support instructors in using ambiguous problems in their classes. Ultimately our project will uncover how students and professional engineers respond to various types of ambiguity. These results will in turn help the professional and academic engineering communities equip future engineers with better instructional materials, methods, and tool kits for handling ambiguous engineering problems.

References

[1] H. A. Simon, "The structure of ill structured problems," *Artificial Intelligence,* vol. 4, pp. 181-201, 1973/12/01/ 1973.

[2] H. A. Simon, "Information-processing theory of human problem solving," in *Handbook of learning & cognitive processes: V. Human information.*, ed Oxford, England: Lawrence Erlbaum, 1978, pp. 271-295.

[3] D. H. Jonassen, "Engineers as problem solvers," in *Cambridge handbook of engineering education*, A. Johri and B. M. Olds, Eds., ed New York: Cambridge University Press, 2014, pp. 103-118.

[4] W. Doyle and K. Carter, "Academic Tasks in Classrooms," *Curriculum Inquiry,* vol. 14, pp. 129-149, 1984.

[5] S. Schrader, W. M. Riggs, and R. P. Smith, "Choice over uncertainty and ambiguity in technical problem solving," *Journal of Engineering and Technology Management,* vol. 10, pp. 73-99, 1993.

[6] E. P. Douglas, S. S. Jordan, M. Lande, and A. E. Bumbaco, "Artifact Elicitation as a Method of Qualitative Inquiry in Engineering Education," in *ASEE Annual Conference*, Seattle, WA, 2015.

[7] K. Charmaz, *Constructing grounded theory*. Thousand Oaks, CA: Sage Publications, 2006.

[8] H. Boeije, "A Purposeful Approach to the Constant Comparative Method in the Analysis of Qualitative Interviews," *Quality & Quantity,* vol. 36, pp. 391-409, 2002.

[9] D. J. Therriault, E. P. Douglas, E. Buten, E. A. L. Bates, and J. A. M. Waisome, "Characterization of Problem Types in Engineering Textbooks," in *ASEE Annual Conference*, Minneapolis, MN, 2022.