WIP: Understanding Ambiguity in Engineering Problem Solving

Marah B. Berry, University of Florida

Marah Berry is a PhD student at the University of Florida studying Environmental Engineering. Her research focuses on engineering problem solving. Her interest for problem solving began while she obtained her M.E. in Systems Engineering at the Pennsylvania State University.

Dr. Elliot P. Douglas, University of Florida

Elliot P. Douglas is Professor of Environmental Engineering Sciences and Engineering Education, and Distinguished Teaching Scholar at the University of Florida. His research interests are in the areas of problem-solving, cultures of inclusion in engineering, engineering ethics, and environmental justice.

Dr. David J Therriault, University of Florida

Dr. Therriault, an Associate Professor joined the College of Education at the University of Florida in 2004. He received his undergraduate degree in psychology from the University of New Hampshire and his M. A. and Ph.D. in cognitive psychology from the University of Illinois at Chicago. Dr. Therriault's primary research interests include the representation of text in memory, comprehending time and space in language, the link between attention and intelligence, the use of perceptual symbols in language, and educational issues related to these topics.

Dr. Jeremy A. Magruder Waisome, University of Florida

Dr. Jeremy A. Magruder Waisome is a Postdoctoral Associate at the University of Florida (UF) and Project Manager of the National Science Foundation Broadening Participation in Computing Alliance: The Institute for African-American Mentoring in Computing Sciences (iAAMCS). She works in the Human Experience Research Lab under the supervision of Dr. Juan E. Gilbert, where she conducts research on broadening participation in science, technology, engineering, mathematics, and computing (STEM+C). Dr. Waisome also works with Dr. Elliot Douglas, who serves as the Director of the Engineering Education Collaborative at UF conducting research related to engineering problem-solving.

Due to her advocacy for diversifying the STEM+C space through evidence-based methods, program support, and mentoring, Dr. Waisome was appointed to serve as Special Assistant to the UF Dean of the Graduate School in the Division of Graduate Student Affairs.

Dr. Waisome earned her B.S., M.S., and Ph.D. in civil engineering from UF. During her studies, she became passionate about issues of equity, access, and inclusion in engineering and computing and worked to develop programs and activities that supported diverse students in these disciplines.

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Abstract
This work in progress paper poses the research question: what are the qualitatively different ways that novice and expert engineers experience ambiguity? 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 solving these complex problems effectively. We present a pilot study consisting of four in-depth interviews with senior civil engineering students. The data collection is ongoing; therefore, our results are not complete. Some preliminary categories of ambiguity have been identified. Once the data set is complete, we will analyze it using phenomenography in order to better understand the variations in these individuals' experiences of ambiguity in engineering problem solving.

Introduction and Background
Understanding how engineers handle ambiguous problems is a common question contemplated by both academic and professional engineers. The difficulty with the present literature is that ambiguity is poorly defined. During problem classification, ambiguity is hardly mentioned and often only identified as a structural element. Little research exists that specifies the possible types of ambiguity and individual differences in how ambiguity is experienced. As a result, there is little research specifying variations of ambiguity or how problem solvers may experience ambiguity differently within the same problem. Schrader, Riggs, and Smith are some of the only researchers to try to operationalize ambiguity specifically in regards to the problem solver [1]. In their work, Schrader, et al. posit that the problem solver confronts two distinct stumbling blocks, ambiguity and uncertainty, when framing the problem space. Ambiguity is characterized as lack of clarity and relationships whereas uncertainty is lack of information. Uncertainty can be reduced by gathering information and building models, whereas ambiguity can be reduced by model building and problem framing.

Problems that are solved by engineers are frequently recognized as ambiguous even though there is little that defines what it would mean for an engineering problem to be ambiguous. There has been a significant amount of research on what types of problems are solved by engineers [2] - [7], yet the primarily focus of this work is on the nature of the problems themselves, not how one makes choices on ambiguity while solving them [8]. Engineering problems are often characterized as well-structured or ill-structured. The literature describes well-structured problems as simple, concrete, having a single solution whereas ill-structured problems are complex, abstract, and often have multiple possible solutions [9], [10]. Jonassen and Hung [10] and Jonassen [6], [11] developed the most frequently recognized typology of problems. Their current classification has ten categories ranging from simple algorithms to dilemma. Another group of typologies was developed by Johnstone [12], Reid and Yang [13], and Simon [14]. They described problems from defined to highly ambiguous. Although this literature provides some guidance in regards to problem complexity, these typologies do not situate the role of the problem solver. The literature explains how epistemic beliefs affect problem solving, yet fails to address how the problem solver chooses and confronts ambiguity. Several disciplines (engineering, physics, chemistry, and mathematics) have studied students' epistemological beliefs and problem solving [14] - [21]. Some of the results suggest a significant relationship between ill-structured problems and epistemic beliefs, whereas others find no relationship. Faber and Benson examined how students' epistemology beliefs affect their goals for problem solving. They found that instructional context played a significant role in how students presented their results [22]. Other research shows that problem-solving strategies can be related to a students' epistemic beliefs [23] and students see a strong disconnect between academic and workplace problems [24], [25]. 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.

Methodology

This work in progress is part of a larger phenomenographic project aimed at investigating different ways that engineering problem solvers experience ambiguity. For this paper, we focus on the initial data that was collected during a pilot phase of the project. Marton described phenomenography as bringing together research on variation across multiple domains and topics under one umbrella resulting in an outcome space defining the variation in the way something can be experienced [26]. Four senior male engineering students studying civil engineering were interviewed on their experiences with ambiguity. Focusing on civil engineering was a pragmatic and theoretical decision. Civil engineers work on complex, ill-structured problems in academic and professional settings making it a good choice from a theoretical perspective. These problems also typically have a social impact (i.e., how will changing traffic patterns increase commute times)?

The interviews used a semi-structure approach in combination with artifact elicitation [27]. Artifact elicitation helps the interviewee clearly describe how they approached a certain problem or process. As artifacts the students brought two or three problems (as artifacts) that they felt were in some fashion ambiguous. The students were asked about their experiences with ambiguity by inquiring about a particular problem's ambiguity and what would change the level of ambiguity experienced. The data analysis followed the approach developed by Frank [28] and Marton [29]. Each transcript is read to identify categories of the ways in which ambiguity is experienced. These categories are then compared with each other and the transcripts to generate a pictorial representation of the hierarchy in how ambiguity is experienced. We are currently in the initial phase of familiarizing ourselves with the data. The quality of the project is being reviewed both internally by the usage of the Q^3 framework [30], [31] and externally by an advisory board.

Findings

The data collection for the entire project is ongoing; therefore, our results should not be interpreted as complete. We have identified a few preliminary categories: perceptions of insufficient information, perceptions that the problem-solving process was unclear, being unsure of their role in group problem solving, and students' feelings (positive & negative) towards ambiguity. We also have assigned four pseudonyms to the students: Jon, Bob, Dave, and Rich.

Insufficient Information

The participants felt that in both the academic and professional setting there have been times they have perceived themselves as lacking information needed to solve a problem. Jon expressed this by stating, "I would say the main thing with an ambiguous question, especially if it's not intended or just the lack of information." Dave gave the example of a problem that involved designing a concrete girder. The number of variables that could be manipulated led to ambiguity for him because there was insufficient information on what values the variables should have.

A general lack of knowledge was also perceived as contributing to ambiguity. When Jon was asked if more time would have helped him to solve the problem he responded, “Yes, I believe to have the knowledge and additionally to be able to do a thorough report.” Dave compared himself to people he considered experts, stating “speaking with people that I’ve worked with on internships and professors who have been in the field for a set amount of time, they see a situation like this and they kind of already know what to expect.”

Problem-Solving Process Unclear

The participants described how there can be ambiguity present in the problem-solving process (i.e., solution path). Bob and Dave both described how problems can have multiple pathways to a solution. As Dave explained for one of his homework assignments, “there’s just multiple ways you can go about it either in instructions or in lecture notes. It was stated there’s multiple ways to go about it, pick whichever one’s right for you.” Similarly, Bob explained how the process can be difficult and ambiguous by stating, “failure is you took the wrong path. So, there must be another path that's the right way, right? So that's ambiguous.” Rich found the same issue in his experience with group problem solving, noting that different groups can take different pathways to the same end result.

The problem solving process can be perceived as ambiguous when a project lacks clear instructions on the outcome. Jon stated, “and the project I guess didn't have a clear description as to what exactly we had to do.” In this case, he was unclear as to what the final outcome should be. Bob also identified unclear outcomes as a point of ambiguity, saying “ambiguity, what's your final results going to be like, it can be a bunch of different things depending on the case, you know.”

Unsure of Role in Group Problem Solving

Ambiguity was described in the context of group problem solving, in that students can be unsure of their role in the group. Bob described his experience with group problem solving as “the first couple weeks you’re with a group it’s everybody sitting around a little bit just waiting who's gonna take the role [of leader].” The lack of leadership led to ambiguity as to how the project would be completed and what each person would be doing. In contrast, Rich described how in his experience ambiguity was reduced because “we communicate together to make sure we’re putting together the same product, that we’re all on the same page.”

Feelings toward Ambiguity

Students also expressed their feelings towards ambiguity. Bob expressed fear and ambiguity together by describing his experience as “I think generally overall speaking ambiguity would be like being in the unknown. Kind of like almost fear of the unknown then like, yeah, you're not sure what you need to do or what is going to be happening.” Jon discussed how taking the wrong path for ambiguous problem increases his anxiety, “if something is too ambiguous…I know I get almost like anxiety if it's ambiguous and I'll never really get going or never know if I'm going in the right direction." Jon's anxiety also became evident when he discussed ambiguity in the workplace versus academia, stating that he "believe[s] that it's kind of like in the school setting if there is something that's ambiguous it should be made known."

Discussion

Our findings start to reveal some interesting differences between the literature on problem-solving and these students' perceptions of ambiguity. In the literature ambiguity is broadly equated with specific structural aspects of the problem to be solved, such as its ill-structuredness [9], [10]. While some aspects of problem structure are evident in the students' experiences, they also identify other contextual aspects as leading to ambiguity. From a structural aspect, lack of information, particularly values for variables, is consistent with Schrader et al.'s definition [1], although what the students call ambiguity Schrader et al. call uncertainty. More generally, ambiguity by the students over the desired outcome reflects the ill-structuredness of the problems.

However, students also perceived a number of contextual factors as contributing to ambiguity. A general lack of knowledge on their part was seen as creating ambiguity as to how to solve the problem. From this perspective, ambiguity would decrease with experience, as noted by Dave. If general knowledge is an aspect of ambiguity, then the differences between novices and experts noted in the literature could be taken as indications of more or less ambiguity in the problem-solving process. Another contextual factor was group problem-solving. The dynamics of group interactions can lead to ambiguity, when group members are unsure of how to proceed with the problem, or reduce ambiguity when roles are agreed upon. Ambiguity is thus connected to team effectiveness, and strategies for improving team effectiveness [32] may reduce perceptions of ambiguity. Finally, students reported having fairly strong reactions with respect to ambiguity. This was manifest in their descriptions of ambiguity contributing to their anxiety or claims that ambiguity should not be in academic settings (without forewarning).

Conclusions

The literature illustrates that definitions of ambiguity have been limited to specific structural aspects of the problem to be solved. In contrast, our findings indicate that additional contextual factors are relevant in students' perceptions of ambiguity. Our project is in its early stages, so at this time we are continuing to collect and analyze data. We expect that additional perceptions and nuances will appear as the project proceeds.

It is evident that engineering problem solvers that are confident in handling ambiguity are needed to solve real world, complex problems. This project will help to inform future studies of engineering problem solving. Having a deeper understanding of the difficulties that problem solvers go through will ultimately help us provide better instructional materials, methods, and tool kits for teaching students how to solve ambiguous engineering problems.

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