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Engineering Faculty's Beliefs About Teaching and Solving Ill-structured Problems

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Abstract

Problem solving is an essential part of engineering. Research shows that students are not exposed to ill-structured problems in the engineering classrooms as much as well-structured problems and do not feel as confident and comfortable solving them. There have been several studies on how engineering students solve and perceive ill-structured problems, however, understanding engineering faculty's perceptions of teaching and solving such problems is important as well. Since it is the engineering faculty who teach students how to approach engineering problems, it is essential to understand how they perceive solving and teaching of these problems. The following research question has guided this research: *What beliefs do engineering faculty have about teaching and solving ill-structured problems?* Ten tenure-track or tenured faculty in civil engineering from various universities across the U.S. were interviewed after solving an ill-structured engineering problem. Their responses were transcribed and coded. The findings suggest that faculty generally preferred to teach both well-structured and ill-structured problems in their courses. They also acknowledge the advantages of ill-structured problems, in that they promote critical thinking, require creativity, and are more challenging. However, the results showed that some are less likely to use ill-structured problems in their teaching compared to well-structured problems. We also found that faculty became more comfortable teaching ill-structured problems as they gain more experience in teaching these types of problems. Faculty's responses showed that while they solve ill-structured problems as part of their research on a regular basis, some faculty do not integrate these problems in the classes that they teach. These results indicate that although faculty recognize the importance of using ill-structured problems while teaching, the lack of experience with teaching these problems, other faculty responsibilities, and the complex nature of these problems make it challenging for engineering faculty to incorporate these problems into the engineering classroom. Based on these findings, in order to improve faculty's comfort and willingness to use ill-structured problems in their teaching, recommendations for faculty are provided in the paper.

I. Introduction and Background

Acquisition of problem solving skills along with specialized knowledge and an integration of process and knowledge to better serve the society are an essential part of the professional education of engineers [1]. Engineers, by definition, engage in problem solving on a regular basis, which has been identified as one of the 21st century skills [2]. However, research has shown that the problem types engineering students and practitioners solve differ [3], [4]. Engineering students are typically given well-structured (also known as well-defined) problems, which have pre-defined solutions. They are used to reinforce recent course material covered in class, and are heavily in a written and well-documented form. Practitioners, however, tackle ill-structured (i.e. complex real-world) problems, which are more vague and ambiguous, require teamwork and complex judgments, and are harder to be defined [5].

The literature shows an abundant comparison of how students and practitioners solve ill-structured problems and what similarities and differences exist between these two groups [6], [7], [8], [9]. The results of these studies emphasize differences between problem solving approaches of students and practitioners. Few studies, however, have examined how engineering faculty solve such type of problems and the variation among their problem solving approaches [10].

In addition to examining how engineering students, faculty, and practitioners solve ill-structured problems, their perceptions about solving ill-structured problems should be explored to improve the civil engineering curriculum. Several studies have been conducted to investigate engineering students' perceptions of ill-structured problems [11], [12], [13], [14]. The results of these studies indicated that engineering students thought ill-structured problems were more difficult to solve than well-structured problems, and reported that they did not feel comfortable solving such problems due to the limited exposure they received in their classes and the ambiguity of the problems. They described them as challenging and complex. These studies shed important light on how students interpret and perceive ill-structured engineering problems given that they will likely be exposed to these problems in workplace environments.

Despite the aforementioned studies on how ill-structured problems are perceived by engineering students, less work has been conducted on engineering faculty's perceptions of teaching and solving ill-structured problems. In one study, Mason [15] explored faculty's perceptions and approaches to problem solving and found that while teaching problems, faculty decomposed the problem into smaller pieces implicitly with a variety of details. Faculty also used reflection as a way of understanding students' problem solving processes as an informal way of assessment. They felt that having students collaborate with each other to solve a problem resulted in informal rather than structured social learning, although they recognized the importance of collaboration in the workforce. In another study, Phang et al. [16] found that the majority of the engineering faculty interviewed could not identify more than three attributes of complex engineering problems and thus suggested training faculty on these attributes of complex engineering problems.

The goal of this study is to examine engineering faculty's perceptions of teaching and solving ill-structured problems. Since it is the engineering faculty who teach engineering students how to solve problems, it is essential to explore their perceptions and interpretations of these problems. The following research question guided this study: *What beliefs do engineering faculty have about teaching and solving ill-structured problems?* Following faculty's responses to interview questions, this study presents themes to aid with the teaching of ill-structured problem solving skills and gain insight into how faculty feel about teaching and solving such problems.

II. Methods

Participants

Participants included 10 civil engineering tenure-track or tenured faculty from various universities across the U.S. To recruit faculty, civil engineering departments at a number of institutions were emailed asking to share the study invitation email with their faculty. Those who responded and volunteered took part in the study. The participants consisted of three females and seven males, ranging in academic age, civil engineering specialization, and level of industry experience (Table 1). These demographics were collected from faculty's responses to a survey.

Table 1. *Characteristics of faculty participants*

#	Gender	Rank	Sub-discipline in CE	Experience in CE industry	Experience in academia as faculty	# of design courses taken
F1	Male	Emeritus Prof	Water resources	5+ yrs FT	5+ yrs FT	5+
F2	Male	Prof	Construction	5+ yrs FT	5+ yrs FT	5+
F3	Male	Assist. Prof	Water resources	5+ yrs FT	Up to 5 yrs FT	Unknown
F4	Male	Prof	Construction	5+ yrs FT	5+ yrs FT	5+
F5	Female	Assist. Prof	Geotechnical	Up to 5 yrs FT	5+ yrs FT	5+
F6	Female	Assist. Prof	Structural	Up to 5 yrs FT	5+ yrs FT	5+
F7	Male	Assist. Prof	Structural	Up to 5 yrs FT	5+ yrs FT	5+
F8	Male	Assist. Prof	Construction	Up to 5 yrs FT	Up to 5 yrs FT	5+
F9	Female	Assoc. Prof	Transportation	none	5+ yrs FT	1-2
F10	Male	Assist. Prof	Construction	none	Up to 5 yrs FT	Unknown

Note: CE = Civil Engineering; FT = full-time

Data Collection

We conducted follow-up interviews with each faculty member after they solved an ill-structured engineering problem [17], [18]. Faculty were first asked to develop a solution to a civil engineering-focused ill-structured problem over a 30-minute period. The ill-structured problem was developed by research team members, including faculty and graduate and undergraduate students following Jonassen's [19] and [20] papers as a reference. The problem that the participants were given was related to removing trash from a polluted river including the following tasks: 1) an annotated drawing and description of the design of a solution, 2) a plan for testing, 3) a list of materials needed, and 4) methodology for construction. We used concurrent verbal protocol analysis (i.e. participants thought out loud while solving the problem) to document faculty's problem solving process and ongoing cognitive activities [21]. After participants developed a solution to the problem, each was interviewed to obtain in-depth insight on their experience with and comfort level in teaching and solving ill-structured problems. Participant interviews and demographics survey data were used as data sources in this study.

The participants were asked a series of 15 interview questions. Since the focus of this paper is to examine how faculty perceive the teaching and solving of ill-structured problems, responses to four of the interview questions (Table 2) were examined. Each interview lasted approximately 25-30 minutes in total. When faculty did not answer an interview question or gave a very brief answer, clarifying and/or follow-up questions were asked where appropriate. Interviews were audio and video recorded.

Table 2. *Interview questions used in the study*

1. Well-structured problems have a single, “correct” solution. Ill-structured problems do not have a single solution – they often have many potential solutions. In the engineering classes that you teach, would you generally say that you teach students to solve well-structured problems? How about Ill-structured?
2. If you had to teach students how to solve such ill-structured problems, how comfortable would you feel? Why? What would help make you feel more comfortable in teaching students the process for solving such problem?
3. Do you solve ill-structured problems on a regular basis for your job? Please explain.
4. If you had to solve this as a problem for your real day-to-day job, is there anything different in how you would go about solving this problem?

Data Analysis

To answer the research question, audio recordings of interviews were transcribed and used for coding purposes. Video recordings of interviews were used to clarify any questions or in case of any inaudible sections. Saldaña’s [22] initial coding (also known as open coding) approach was employed to “*remain open to all possible theoretical directions*” [23] and closely examine the similarities and differences between the transcripts. First, initial codes were developed by researchers through an analysis of each of the responses in the transcripts. Next, these codes were combined and refined, and themes were developed. Five members of the research team developed the codes iteratively, resulting in the final codes in Table 3. The main codes listed in Table 3 were informed by our interview questions and sub-codes under each main code were developed by the same research team upon reading through the transcripts. Each transcript was coded by two researchers to ensure 80% reliability was reached. A third coder’s assistance was used when there was a disagreement between the two coders. Interviews were coded using MaxQDA Analytics Pro [24]. Upon coding of the 10 transcripts, they were merged into a single file to analyze common themes among them.

Table 3. *Coding scheme used for the study*

Main Codes	Definition
Problem type taught by faculty	a) Whether they teach ill-structured, well-structured or a combination of the two b) reasons for teaching the preferred problem type(s), and c) reasons for not teaching a certain type of problem
Feelings about teaching ill-structured problems	a) Whether they feel comfortable or not teaching ill-structure problems, b) why, and c) what would make them feel more comfortable
Frequency of solving ill-structured problems	a) Whether they solve ill-structured problems on a regular basis and b) why and for what purpose
Difference in problem solving strategy in real-world scenario	a) What they would do differently to solve the problem in a real-world setting

III. Results

We identified several main themes based on analysis of the coded manuscripts. These are as follows.

Theme 1. Most faculty teach a combination of well-structured and ill-structured problems. They teach well-structured problems to teach a principle, concept, and theory due to their structuredness; they include ill-structured problems to have students apply a theory and use their creativity.

Seven of the faculty responded that they teach a combination of well-structured and ill-structured problems while two teach only ill-structured and one faculty teaches well-structured problems in their courses. When asked about the reasons behind these decisions, the responses varied. The faculty who stated they teach well-structured problems (F5) mentioned that they do so because well-structured problems are easier to grade and that ill-structured problems are a challenge particularly for large courses and for grading. The same faculty added "*As a systematic learner, I like things that are step-by-step. As you saw when I worked the word problem, I would write down the knowns as I was working in the problem.*" while recognized that ill-structured problems promote students' critical thinking. This shows that faculty's personal learning styles (i.e. systematic in this example) could be a factor in determining what type of problem they would rather teach. The two faculty who stated they teach ill-structured problems mentioned that they try not to give students well-structured problems because "*real life is not a well-structured problem*" (F10). They emphasized that life is not black and white and that to prepare students for life, students should be given the chance to consider multiple ways of solving a problem.

For the seven faculty who teach both types of problems, F1 stated that they use well-structured problems to introduce a theory, however when they want students to apply their knowledge of theories, then they give students ill-structured problems. The level of courses faculty teach also played a role in their decision of what type of problem to give students. For instance, F3 recounted: "*It's a spectrum from let's say, at the 200 level, it might be 90% well, 10% ill. At 300 level, it might be 65% well-structure, 35% ill-structured*." This indicates that this faculty integrated more ill-structured problems in senior and junior level courses than the lower level courses, which aligns with the number of design courses that senior and junior students take compared to freshman. Other faculty (F4, F7, F8) stated that the reason they give students ill-structured problems is that these problems stimulate critical thinking, promote creativity, and have students go through a series of assumptions while well-structured problems help them learn engineering concepts. In addition, two faculty (F6 and F9) mentioned that the type of problems that they teach depends on the content of a course. For example, F9 stated that when they teach transportation engineering, they solve more well-structured problems while in an engineering policy class, they teach more ill-structured problems. As seen in these responses, several factors such as faculty's personal preferences and learning styles, the course content, and the level of courses they teach impact their decision about what problem type they would give their students.

It should be noted that when the first interview question was asked (Table 2), one faculty (F4) disagreed with the given definition of an ill-structured problem before answering the question. They stated that well-structured problems can also have more than one correct answer and that "*I think that both are well-structured because in life, problems aren't necessarily defined exactly or there's no one right answer. A good problem that is structured well can be one that has many answers because that's what we see in life."* This shows that not all faculty may have the same understanding of a well-structured and an ill-structured engineering problem, which may have influenced their response to this interview question.

Theme 2. The more experience faculty have in teaching ill-structured problems, the more comfortable they feel teaching ill-structured problems. Most faculty noted that teaching such problems required extra work and time, highlighting that availability of an evaluation matrix and case studies and working closely with practitioners could help them feel more comfortable.

Four faculty stated that they feel comfortable teaching ill-structured problems and that this was mainly because they had experience in teaching such problems and thus feel more confident about the subject matter and problems, as in the following example: "*Do I feel comfortable doing that? I've been doing this a long time, almost 20 years, so I think I feel comfortable by now. After a while, when you teach the class a long time, you know the ins and outs of that. I think that helps give me confidence"* (F4). Teaching the same course where students solve more open-ended problems also played a role in making them feel comfortable. Three faculty, however, indicated that they do not feel comfortable teaching ill-structured problems, arguing that they teach more than one course and due to a lack of time, it is difficult to integrate these problems in their classes. They also mentioned that integration of open-ended problems requires extra effort and time for faculty. For example, F7 mentioned the challenges that come with teaching ill-structured problems by saying "*Even for me is very difficult because these kinds of design, creative design problem, involves potentially many, infinitely many solutions. What I have to guide them and then persuade them why this is not a good idea. Why is it a good idea? So it's very challenging every time, every semester*." This example shows that because ill-structured problems have more than one potential solution, it makes it challenging for faculty to explain why some solutions could be more acceptable than others. Another faculty (F10) mentioned that it also makes it hard to deal with students, as students are used to having a right or wrong answer, as shown in the following example: "*I do not feel comfortable because of all the "nagging" that I did afterwards… Especially when you grade their assignments or when you grade their exams and you give them that feedback that says that this solution is not right, then they come to you and they're like, "Why it's not right?" If I had a black or white and someone said, "Why it's not right?" I can tell them, "Well, the answer is white and you answered the black, so that's it." There is no arguing after that. This type of question, no, you have to take the student in and explain for 15 minutes what they have done wrong…*" As seen in these examples, some faculty feel that when they teach an ill-structured problem, this requires significant extra effort and time to explain students why some solutions are not correct, which may create additional demands for them given their other responsibilities.

When asked what would make them more comfortable teaching these problems, responses varied from involving practitioners in the teaching process and exposing students to these problems earlier, in their freshman and/or sophomore year. Three faculty mentioned that it requires more effort to grade ill-structured problems than well-structured problems and suggested having more guidance as to grading these types of problems, such as a rubric or an evaluation matrix that could help them provide more structured, objective feedback. In addition, one faculty (F8) suggested integrating more case studies and real-world-examples to teach these problems and that having students work in groups to solve problems would make them comfortable. Another faculty (F7) stated that if they watched practitioners solve ill-structured problems, it would help them feel more comfortable integrating such problems in the classroom. For involving practitioners in the engineering classroom, F7 suggested: "*What would make me feel more comfortable is that real engineers are involved. Instead of having to rely on me to say if the solution is a good solution or not because I have a limited real-world experience, much of my experience is been an academia or short term internships. I feel much more comfortable with engineers with years of experience to say, "Oh, yes this will work, this won't work", "there's some reasons why it's a good solution one that could be improved*." In addition, one faculty recommended starting to introduce ill-structured problems in K-12 education or in the first and second year of college. They stated that if students came to college knowing that everything is not black or white, it could help both faculty and students feel more comfortable solving these problems.

Theme 3. Most faculty state they solve ill-structured problems, however these problems are typically research-focused. For those that state they do not, other time-intensive job requirements and challenges are reasons for them not solving ill-structured problems.

When asked whether they solved ill-structured problems on a regular basis, eight faculty responded yes and stated that they solve such problems for research purposes (6 faculty) and as part of their position requirement (2 faculty). For instance, F2, who was an Associate Dean, recounted "*If it's an ill-structure problem that means it's mine, which I have to figure out what the real question is, what the resources are and we can help with that, get the right people in the room and then move forward from that standpoint. Most of what I do is ill-structured I would argue*." Six faculty who noted that they solve ill-structured problems for research purposes stated that they typically solve ill-structured problems in research which cannot be solved with an existing, straightforward method, nor do they have a correct solution. Faculty explained that this is the nature of research, as shown in the following example: "*If there's a problem that has a straightforward solution, or a solution for which there is an existing technique, for instance, to model the scenario that's used in practice, then a researcher doesn't get called into the picture. The reason that people come to us as researchers is because there's a problem that doesn't have an existing technique or there's not an existing model to model what needs to be modeled. Certainly, the ill-structured problem is basically all that I deal with in terms of practical engineering*" (F3). This shows that while faculty solve research ill-structured problems, the way they view industry ill-structured problems differs, which may indicate two different possible methods to solving these problems.

The two faculty who mentioned they do not solve ill-structured problems on a regular basis stated that they solve other types of problems such as "*how to structure a class*" and "*how to write a tenure recommendation letter*" (F9) and that they do not have time to solve ill-structured problems due to dealing with politics and networking. This indicates that due to non-research responsibilities, some faculty do not think they solve such problems, which may suggest why there is discomfort in teaching ill-structured problems and thus a lack of integration of these problems into the engineering classroom. It should be noted that these two faculty also thought that teaching ill-structured problems creates extra work for faculty. This may also suggest there are other factors influencing these responses which were not probed in the interview process.

Theme 4. If faculty were to solve the same ill-structured problem in a real-world setting, most stated they would get help from colleagues for revision of their solution and conduct more research.

When asked what they would do differently to solve the problem in a real-world situation (i.e. not in a 30-minute timeframe), faculty's responses varied. Several suggestions include collaboration with others. Specifically, two faculty stated that they would have other peers and/or professionals review their work. For example: "*In practice, I would actually have an outside agent review the work because they have fresh eyes and can see things that the person who did the work might not see*" (F1). Another faculty mentioned that they would form a team.

Several faculty stated they would work further on the solution. Two indicated they would add more details in the methodology, list of materials, and instructions. Five faculty suggested additional initial information gathering and background research online. One faculty stated that they would do actual calculations to come up with a quantitative answer using spreadsheets to calculate the cost and size of the design.

IV. Conclusion

The goal of this study was to explore the perceptions of civil engineering faculty on teaching and solving ill-structured problems, how comfortable they feel about integrating these problems in their classes, and the influential factors impacting these perceptions. The study showed that the majority of faculty incorporated both well-structured and ill-structured problems into their classes due to several reasons. In general, faculty expressed that teaching ill-structured problems requires additional effort and time of which they have limited amounts, and that including practitioners and grading tools along with real-world examples may help them increase their comfort level in teaching ill-structured problems. It was found that the majority of faculty solve ill-structured problems for research purposes but that they view this as different than an industry real-world problem.

The results revealed that while most faculty solve ill-structured problems on a regular basis for either research purposes or as a job requirement, some still do not feel comfortable teaching them. This shows that although faculty tackle such problems regularly, it does not mean that they would transfer their knowledge or the ill-structured problems they solve for research purposes into the courses that they teach, as they feel uncomfortable and not experienced. This indicates that they need more support in the teaching of these problems. Based on faculty’s responses, we recommend having faculty observe practitioners solve ill-structured problems, observe courses where ill-structured problems are implemented, or put faculty in touch with other faculty who have more experience in teaching such problems. Another recommendation is to provide case studies and training courses for faculty and make universal rubrics available that they can use to guide the grading of ill-structured problems. Including practitioners in the teaching of these problems such as inviting them as guest speakers to engineering classes or involving them in the grading of these problems could motivate and improve comfort levels of engineering faculty in teaching such problems. Given that faculty are busy with teaching, research, and other responsibilities, as mentioned by several faculty, integrating designated opportunities to learn best practices and teaching techniques for ill-structured problems, and resources for real world problems may also make them more comfortable integrating such problems in their courses.

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