ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #38409

# Perspectives of Engineering Faculty and Practitioners on Creativity in Solving Ill-Structured Problems


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## Abstract

Creativity plays an important role in engineering problem solving, particularly when solving an ill-structured problem, and has been a topic of increasing research interest in recent years. Prior research on creativity has been conducted in problem solving settings, predominantly focusing on undergraduate engineering students, including how faculty can foster creativity in engineering students, how engineering faculty perceive their students' creativity, and how to measure it. However, more work is needed to examine engineering faculty and practitioner perspectives on the role of creativity when they solve an engineering problem themselves. Since engineering students learn problem solving, at least initially, mainly from their professors, it is essential to understand how faculty perceive their own creativity in problem solving. Similarly, given that practitioners solve ill-structured engineering problems on a regular basis in the workplace and that most of the students go on to work in the engineering industry when they graduate and ultimately become practitioners, it is also important to explore practitioner perspectives on creativity in problem solving settings. As part of an ongoing NSF-funded study, this paper investigates how engineering faculty's and practitioners' creativity influences their problem solving processes, how their perspectives on creativity in a problem solving environment differ, and what factors impact their creativity. Five tenure-track faculty in civil engineering and five practitioners were interviewed after they solved an ill-structured engineering problem. Participants' responses were transcribed and coded using initial coding. This paper discusses their responses to semi-structured interview questions. The findings suggest that faculty and practitioners feel more creative when they are familiar with the subject area of a problem. If they are aware of a particular solution that has been developed and used before or have access to resources to look them up, they may not necessarily embrace creativity. The findings indicate differences not only across faculty and practitioners but also within the faculty and practitioner participants. Similarities and differences between faculty and practitioners in creative problem solving and the themes that emerged are discussed and recommendations for educators are provided.


## Introduction and Background

As one of the important and encouraged skills in engineering education, creativity has been widely studied in the literature. The Accreditation Board for Engineering and Technology (ABET) [1] defines engineering design as creative, in addition to being iterative. Similarly, according to a report published by the Royal Academy of Engineering [2], one of the six principles of understanding the challenges of a design problem is being creative. Given that creative problem solving is a vital part of engineering [3], it is essential to examine how creativity is facilitated in the engineering classroom and perceived by engineering students, faculty, and practitioners.

Fostering engineering students' creativity when solving a design problem has been considered as one of the important goals in engineering education [4]. One way this has been studied in the literature is through understanding student perceptions of creativity [5], [6], [7], [8]. Tolbert and Daly [8] found that how faculty encourage creative problem solving in engineering classes (in words and actions) impacts student creativity. They also found that students' domain knowledge, team-related challenges, and project constraints such as time influence creative problem solving. In another study on student perceptions on creative problem solving, Kazerounian and Foley [7], found that engineering students believed their professors do not place enough value on creativity. They also found that when solving problems, students have a tendency to rely on "*old solutions over innovation and possible improvement"* (p. 767). In addition, students felt that they were not taught to have an open mind while solving problems and did not develop multiple solutions. The findings of the same study also revealed that when compared to students in humanities and sciences, engineering students were the ones who had the most "room for creativity improvement".

Research shows that students who value creativity in engineering design tasks and believe that they are creative, are more likely to generate creative solutions when solving design problems [5]. As such, in the teaching of creativity in engineering students, faculty and practitioners play an important role. Engineering students learn how to solve problems through the lectures and classroom activities provided by faculty and experiences outside of academia such as internships where they have an opportunity to solve real-world problems with practitioners. Thus, engineering faculty and practitioners act as role models in developing and facilitating creative problem solving. Most of the studies on faculty perceptions of creativity focus on how they foster and perceive the creativity of their students [7], [9], [10]. One study [7] found that instructors believed engineering education lacks creativity and that engineering instructors "*are doing an insufficient job of passing on creativity inducements to students*" (p.766). One way instructors developed creativity in students was to reward students who take risks on projects.

A few studies explored how practitioners perceive creative problem solving [11], [12], [13]. In one study on practitioner perspectives on creativity in everyday practice, Cybulski et al. [13] found that practitioners considered lack of broad experience as a barrier to creative problem solving. They believed that real-world experience more than traditional education, teamwork, and organizational culture, greatly influence generating creative solutions. Likewise, the findings of Belski et al. [12] revealed that practitioners believed wide-ranging experience rather than domain knowledge is the key to solving problems creatively. Defining creativity as thinking 'outside of the box', practitioners thought understanding a problem and learning creativity methods were important elements of creative problem solving.

In the literature, it is recommended that faculty incorporate creative thinking into their syllabus, see value in creativity (not only by giving advice to students verbally but showing it in their actions), and encourage creative problem solving by providing opportunities for their students to be creative, such as giving them flexibility to explore new ideas. While these studies have examined perceptions of engineering students, faculty, and practitioners on creativity with more emphasis on student creativity, more work is needed on how faculty perceive their own creativity when solving engineering problems. Engineering students learn creative problem solving through examples of creativity discussed and/or demonstrated by the faculty in the classroom and may mimic their professors as they watch faculty work creatively in problem solving settings. Likewise, engineering students solve real-world problems with practitioners during their internship and/or co-op experiences or when they start working in the industry. Thus, in this study we explored engineering faculty and practitioner perspectives on creativity when they solve an ill-structured (open-ended and complex) problem, how their perspectives differ, and what impacts their creative problem solving, following their responses to interview questions.

## Methods

### *Participants*

Participants included five faculty from various universities across the US and five practitioners. All of the practitioners had more than five years of work experience in the civil engineering industry without any significant employment in academia. They all took more than five design courses as undergraduate students and their specialization was in transportation and structures within civil engineering. Faculty participants consisted of two assistant professors, two associate professors, and a full professor. Their specializations included structures, construction, geotechnical, and water resources. One faculty had more than five years of work experience in the civil engineering industry, two had between 1-5 years of employment in industry, and the other two did not have significant industry work experience. Table 1 summarizes the characteristics of the participants. Note all names included in this table are pseudonyms.

### *Data Collection*

The data used in this research includes responses of faculty and practitioners to semi-structured interviews conducted after participants solved an ill-structured problem from the civil engineering domain. Participants were asked to solve an ill-structured problem about how to remove trash from a polluted river, and given 35 minutes to do so [14], [15]. Using verbal protocol analysis, they were asked to think out loud while formulating a solution to the given problem. After they finished working on the problem, a follow-up interview was conducted with each participant to gain in-depth insights into their perspectives on creativity in problem solving and what factors impacted their creativity in the process of solving of a problem. Participants were asked the following questions: "*If you were asked on a scale of 1 to 10 how creative you are, what would you say and why?"* and *"Do you think that influenced how you solved the problem?"* Each interview was audio recorded.

### *Data Analysis*

An initial coding (i.e. open coding) approach [16] was employed to analyze the data. Through initial coding the data was divided into segments, which were then compared for similarities and differences. First, audio recordings of interviews was transcribed and the transcripts were read by research team members iteratively. Next, initial labels were developed after reading the transcripts. These labels were combined and refined based on the similarities and differences across the transcripts. Two researchers coded each transcript and a third researcher was consulted in case of disagreements. MaxQDA Analytics Pro [17] was used to code the transcripts.

Table 1. *Demographics of participants*

| Parti-cipant | Role | Gender | Field | # of design courses taken | Work experience in industry | Work experience in academia | Participant creativity rating |
|---|---|---|---|---|---|---|---|
| **Lisa** | practitioner | female | transportation | 5+ | 5+ years FT employment | no significant employment | not reported |
| **Jennifer** | practitioner | female | transportation | 5+ | 5+ years FT employment | no significant employment | not reported |
| **Amy** | practitioner | female | structural | 5+ | 5+ years FT employment | no significant employment | 6 |
| **John** | practitioner | male | structural | 5+ | 5+ years FT employment | no significant employment | 5 |
| **Michael** | practitioner | male | structural | 5+ | 5+ years FT employment | no significant employment | 7 |
| **Jason** | assist prof | male | water resources | not reported | 5+ years FT employment | up to 5 years FT as a faculty member | 8.5 |
| **David** | assist prof | male | geotechnical | not reported | up to 5 years FT employment | up to 5 years FT as a faculty member | 6 |
| **Sarah** | associate prof | female | structural | 5+ | up to 5 years FT employment | 5+ years FT as a faculty member | 6 |
| **Matthew** | associate prof | male | construction | 5+ | no significant employment | 5+ years FT as a faculty member | 10 |
| **Angela** | prof | female | structural | not reported | no significant employment | 5+ years FT as a faculty member | 5 |

*Note: FT = full-time, Participant creativity rating is out of 10.*

## Results

In this section, responses of practitioners and faculty to interview questions are discussed. Pseudonyms are used to refer to participants to protect their anonymity (see Table 1).

### *Practitioners*

Two practitioners reported that their creativity fluctuates based on the subject. Jennifer, for example, mentioned that she feels more creative when solving a construction-related problem but not in other fields such as *art*, where she does not feel creative. She stated that in terms of coming up with new ways to ensure that her contractors stay on schedule, she feels creative and added "… *I would say I can be creative, but it has to be in my wheelhouse of expertise*." This shows that familiarity with the subject might play an important role in making practitioners feel more creative. As suggested by Belski et al. [12], this aligns with the statement from practitioners from prior research that suggests understanding the problem is important to support creativity, which would suggest that some domain knowledge is helpful for facilitating creativity. However this statement also appears to somewhat contradict other components of creative literature that suggest that wide-ranging experience rather than domain knowledge is important for creativity. This interesting and somewhat contradictory groups of thought are demonstrated further in the practitioner and faculty responses.

When practitioner Michael was asked about his self-assessed creativity level, he made a comparison between engineering and other fields and reported that his creativity is a seven out of 10 and added "*which is why I am an engineer, not an architect*." He said that his solution was visually less appealing but economical and effective and added that it was not something he would submit for a competition to receive a prize. Michael's response shows that creative solutions may be considered to be more visually appealing and "*beautiful*" but may not necessarily be economical and effective. The comparison between engineering and architecture may indicate that engineers perceive architects as more creative than engineers, and also that engineers may be more practical, or at least expected to be so. This theme of practicality in engineering solutions is seen in other responses as well, as discussed below.

Two of the practitioners utilized more of what they had seen before to solve the problem. Lisa stated that *"I'm not big on reinventing the wheel. I'm not big on coming up with new solutions for things…"* She developed a netted trash collector system and said "*I am influenced by other things rather than being creative on my own."* Similarly, Amy indicated that she believed that not many engineers are creative, as the solution should be tried and true in engineering, somewhat similar to the statement from Michael about engineering solutions needing to work, i.e. be economical and effective. Amy also mentioned that a completely creative solution would not be achievable due to the constraints given in the problem.

These statements suggest three key themes. First is that some domain knowledge related to a problem is helpful in allowing engineers to be creative. However, second, knowledge of existing solution(s) to the specific problem being solved impacts a practitioner's ability to be creative. In this case they may not necessarily use their creativity to develop a new solution when one is already known to exist and work. A third theme seems to suggest that practitioners may feel restricted by expectations, specifically that they are expected to develop a working, practical solution within specific design constraints, and thus they may not feel creative.

In addition, practitioners associated creativity with coming up with multiple solutions and thinking outside of the box. John, who self-assessed his creativity as five out of 10, said that "*I got stuck on one solution, it was hard to think really of alternative ways and so I had one*."

*Faculty*

Familiarity with the problem and past experience also impacted faculty's creativity. With her self-assessed creativity five out of 10, Angela said she did not feel comfortable with the problem because she thought she would need a "*practical solution*." This clashing between practicality and creativity is consistent with practitioners Michael and Amy's statements, and the third above-mentioned theme. Angela added "*I feel like my creativity fluctuates quite a bit. I think it depends on how familiar I am with the topic*." This is similar to Jennifer's statement of a topic needing to be in her "*wheelhouse of expertise,*" i.e. the first above-mentioned theme. When asked what would help her creativity improve, she responded that having more information about the problem, visiting the site in person, and having more visual information may help with the brainstorming of ideas and be more creative during the problem solving process.

Similarly, past experience with the problem influenced David's creativity who stated that "*I will go for 6 for the creative solutions, but I will always develop a solution based upon the past experience that happened*." He stated that if he is familiar with the problem and feels comfortable solving it, he can be more creative, but if he sees a problem for the first time, he will look up previous solutions to the problem. Specifically he mentioned "*If I'm comfortable and if I have the past experience… I can be absolutely creative. If something like this, all of a sudden, I am seeing for the first time, I'll just look for the past solutions…and then try to use that knowledge to provide a solution.*" He mentioned that his creativity fluctuates depending on how much risk is involved in the project and that he would rather be on the conservative side rather than developing a risky creative solution. David's comments on prior experience appear to be consistent with the first theme noted from practitioners as well as Amy's comments suggesting that some domain knowledge is helpful. They also appear to reflect the third theme of practicality, and that a "creative" solution may also be perceived as "risky", with a negative connotation.

One faculty associated creativity with not making use of an existing design. Jason rated his creativity 8.5 out of 10 and stated that he has a more tendency to embrace creativity than other engineers, as he tries not to use the Internet while solving a problem and instead starts from scratch thinking of the best possible solution. Similar to Jason, Sarah spoke about having access to resources such as the Internet while solving a problem and said that if such resources were available to her, she would just google them to see what other people did and replicate their ideas, which she thought in such cases she would be less likely to be more creative. This is consistent with the second above-mentioned theme. She added that in our problem solving setting where she was not provided any outside resources "*I think given this particular example where I had no other background knowledge I was forced to dive a little bit more into my creativity*." These examples of Jason and Sarah show that faculty may feel more able to use their creativity when they are not provided with outside resources such as the Internet.

Matthew, an associate professor, approached creativity and what impacts it from a different perspective when compared to other faculty participants. He highlighted the importance of problem definition in the use of creativity. As someone who studied bridge engineering and is now teaching in construction engineering and management with his research focusing on information technology and robotics, he reported that when solving a problem, he would rather define the problem as best as he can and highlighted the importance of wide-ranging domain knowledge to formulate creative solutions. The importance of some domain knowledge, however, is consistent with the first theme seen in practitioners.

## Discussion and Conclusions

This study explored how engineering faculty and practitioners perceive creativity in solving an ill-structured engineering problem, what factors influence their creativity in a problem solving setting, and how their perspectives on creative problem solving differ. Participant responses indicated that there are multiple reasons that influence faculty's and practitioners' creativity. The reasons vary from how much risk is involved in the project, whether they are comfortable and familiar with the problem, and if they have access to outside resources. Faculty's and practitioners' perspectives on creative problem solving showed similarities and differences. In terms of similarities, three main themes emerged. Specifically:

**(1)** Faculty and practitioners believed that they feel more creative when they are familiar with the subject area of a problem (i.e. have some domain knowledge). Interestingly, what is suggested in the body of literature on creativity of having broad background knowledge in different domains (e.g. [12-13]) was mentioned by only one participant. However this does not necessarily mean this is not important. It may suggest, however, that this is not widely recognized by faculty and practitioners as an important component to creativity.

**(2)** If faculty and practitioners are aware of a particular solution(s) that has been developed and used before or have the ability to look them up, they do not necessarily embrace creativity, and tend to use the prior solutions to address a given problem that are known to work. This is not surprising, given how accessible information and data are today with the ubiquitous availability of and access to the internet and other relevant resources. This may suggest that if creativity is being encouraged in the problem solving process, access to these materials should be initially limited.

Third, **(3)** is their feeling of limited ability to be creative in highly unfamiliar domains, or when seeing a problem for the first time, because of the expectation for their resulting solutions to work. As engineers, and particularly civil engineers, there is an expectation and potentially even a perceived obligation that our work results in a solution that is not at high risk for failing, and that proposing a solution that we are not sure "works" may impact how others perceive us as engineers. In many civil engineering curriculums case studies of engineering designs that caused loss of life and/or catastrophic failure of infrastructure system(s) are used to emphasize engineering ethics. This theme may stem from such training and resulting sense of moral obligations.

Regarding differences, practitioners associated creativity with developing multiple solutions to a problem and thinking outside of the box. Faculty participants did not mention these. On the other hand, faculty brought up having access to resources and how it impacts their creative problem solving. They tend to be less creative when resources such as googling similar problems on the Internet are available to them. This was not mentioned by practitioners. This particular example may not have been mentioned by practitioners because likely most practitioners do not use the Internet as a primary resource for looking up solutions they encounter to problems. Likely they use internal resources to their company and/or professional industry.

It should be noted that we found differences not only across faculty and practitioners but also within the faculty and practitioner participants. One example of this is that while some practitioners used a previous solution rather than "reinventing the wheel", some practitioners associated creativity with "thinking outside of the box" and came up with a new solution. Similarly, while some faculty mentioned that they are more creative when they are familiar with the subject, some felt more creative when they start from scratch without taking previous solutions into consideration and using outside resources. These differences within the faculty and practitioner participants may result from their personal problem solving approaches and demographics, and are worthy of future investigation. They may also indicate that faculty and practitioners might have a different definition of creativity and future studies could explore how creativity is defined by faculty and practitioners.

Overall, given the above-mentioned themes, the following are recommendations for teaching creativity for civil engineering:

- Given that both faculty and practitioners feel more creative when familiar with a problem, we recommend faculty and practitioners have more exposure to different subjects within engineering problems, and similarly they expose students to a similar diversity of subject areas and experiences. In this way, faculty with more familiarity with different problems could come up with more creative solutions and better teach these skills to engineering students. Similarly, practitioners as guest speakers in engineering classes, supervisors during internships, and mentors and colleagues when undergraduate students start working in the industry could help engineering students be familiar with more creative solutions to engineering problems in their journey of becoming future innovative engineers.
- Faculty from other fields such as architecture and arts could be invited to senior design courses to work with engineering students to improve their creativity given that architects are perceived as more creative than engineers.
- We also recommend that brainstorming without access to outside resources when solving a problem should be encouraged based on the finding that some feel more creative without using such resources.
- Given that some faculty and professionals appear to associate creativity and higher risk solutions that may be perceived as impractical, this may be a feeling that is also projected to students when learning the problem solving process. As such, in teaching students to be creative, perhaps it needs to be explicitly stated in the teaching of problem solving methods that creative solutions are allowed, encouraged, without initial judgement as to their practicality. This would provide a non-judgmental forum in which students could innovate without the perceived threat to how they are perceived as an engineer.

This exploratory study allowed us to depict perspectives of faculty and practitioners on creative problem solving. Although our findings cannot be generalized to other engineering faculty and practitioners, we believe this study contributes to the field as a useful step in understanding faculty's and practitioners' beliefs about their own creativity in solving ill-structured problems. Moving forward, we will collect data from engineering students to examine their perspectives on creative problem solving and compare their results to those of faculty and practitioners.

**Acknowledgements**

This material is based upon work supported by the National Science Foundation under Grant No. 1712195/2013144 and any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. We thank Yiqi Liang for her efforts to code the transcripts.

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