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Creativity's Role in Solving Ill-Structured Engineering Problems: Opinions of Student, Faculty and Practitioners

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Abstract

Research has shown the need to explore creativity in the context of engineering curricula, including when solving complex design problems where there is not one correct solution. To further understand the relationship between creativity and engineering ill-structured problem solving, in this paper, semi-structured interviews were conducted, transcribed, and coded after faculty members, practitioners, and undergraduate students were asked to solve an ill-structured engineering problem. In this follow-up interview, 37 undergraduate students ranging from freshman to fifth-year senior (in addition to 19 faculty members, and 11 practitioners) in civil engineering were asked to explain the impact of creativity in the problem solving process, and also were asked to complete a creativity survey (K-DOCS). This paper discusses common themes shared among faculty, practitioners, and undergraduate engineering students, including varied creativity scores (self-rated and measured), and different opinions among participants with various levels of problem solving and engineering fieldwork experience in defining being creative (or not) in solving ill-structured engineering problems.

The collected data reflects that the three groups have a variety of definitions of being creative (or not) throughout the problem solving process. Common themes include the following: Undergraduate students focus on relating creativity to generating multiple original ideas, and generating ideas that are extravagant and/or out of the box. This is different from faculty members which consider creativity to come from accumulated background knowledge and past experiences, and engineering practitioners which more often consider the safety- and risk-related considerations when working towards developing solutions to problems. In addition, a theme discussed was that creative solutions may be considered to be not as effective and/or realistic, and may be more risky. The data and results of this project provide insights for educators in the engineering field to incorporate domain of knowledge or experience that would help to support college engineering students' engineering problem-solving, and to help students work toward solutions that are both creative and that will work.

Introduction and Rationale

Individuals choose to pursue a degree in higher education to establish a foundation for their future careers. Therefore, the design of engineering curriculum at the college level needs to provide students with the necessary skills to be able to solve real-world problems in the field of engineering. "Ill-structured" problems, also described as "wicked", "ill-defined", "complex", or "workplace" describe problems which do not have defined correct solution, are not easily described, lack defined rules, and often necessitate iteration to generate a final solution [1] [2]. These types of problems solved in a classroom environment are meant to mirror real-world situations that future engineers may encounter in their careers. Having problem solving experiences, especially ill-structured problem solving experiences, as an engineering student is important, as suggested by the Accreditation Board for Engineering and Technology (ABET) in Outcomes 1 and 2 [3].

In the development of problem solving skills, research suggests that creativity can be an important factor influencing the solving of such problems. Goodman and Frezza [4] explain the relationship between ill-structured problems and creativity as "ill-structured problems inherently require creative exploration by those charged with their understanding and solution, and this implies more than one right answer." This paper thus focuses on the impact of creativity in this process through the lens of undergraduate engineering students.

It is generally agreed upon that the teaching of ill-structured problems in the STEM curriculum is important. However, more research is needed to understand students' creativity as a part of this process, as students are those learning through experiences that will soon transfer their classroom-learned knowledge into real-world practice. This research aims to examine the common themes shared among engineering students regarding their creativity level as it relates to solving ill-structured problems. While researchers continue to explore ways to evaluate the competence of solving ill-structured problems, we investigate creativity as an element through individual reflective interviews.

Research Methods

Participants & Data Collection

As a part of a broader study on ill-structured problem solving, three groups of participants from civil engineering were asked to solve an ill-structured problem over a 35-minute period. The focus of the ill-structured problem is the development of a solution to remove trash from a polluted river. For more information on this problem and preliminary results regarding the problem solving process, see [5]. Following this problem solving exercise, participants were asked to answer follow-up interview questions, several of which related to creativity. More specifically 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. Each participant was also asked to complete a creativity assessment using a validated assessment tool, the Kaufman Domains of Creativity Scale - K-DOCS [6]. Participants do not have to access to interview questions prior to experiment's date and time. Participants were not prompted to give a definition of creativity, nor provided any instruction on what constitutes creativity. We also note that our previous research considered the perspectives of engineering faculty and practitioners on creativity and solving ill-structured problems [7]. This research builds on this previous publication, and provides the third perspective, that of students, which can be compared to the findings of the prior publication.

37 undergraduate students in civil engineering ranging from first to fifth-year seniors are the main group of participants in this study, and are the focus of this paper. Within this student sample group, there are 6 first, 3 second, 13 third, 10 fourth and 5 fifth-year seniors. Some students had experience in real-world engineering scenarios through their participation in internships. However, the types of experiences and engineering jobs they had completed, as well as the number

of design-focused courses they had taken varied. In addition, 19 faculty members and 11 practitioners were also asked to solve the same ill-structured problem and complete the follow up interview [7]. These are mentioned as their responses are used to compare to the undergraduate students' creativity-related responses.

Analysis and Interpretation of Data

After the individual transcripts were generated for each participant from the follow-up interviews, these transcripts were reviewed and used to generate common themes related to creativity. Student participants' responses were coded in themes that best describe participants' understanding of the relationship between their self-rated creativity levels and their ill-structured problem solving process. This was completed by a team of multiple researchers who reviewed similarities and differences in topics across all transcripts. Subcodes mentioned in this code system were, in some cases, refined and/or combined as compared to the previous study [7] to better understand common themes shared in creative problem solving across students, faculty, and professionals.

Table 1 shows the creativity-related codes associated with student participants' responses to the above-mentioned questions. These are subdivided into two categories depending on if the participant's response to the question on whether they were creative or not was 5 or less (i.e. "not creative", right column), or 6 or more (i.e. "creative", left column). These are grouped this way because once a participant stated their self-rated creativity score from 1 to 10, they were asked to explain why and how this influenced their response to the ill-structured problem. Thus, in general, if a participant stated they were *not* creative, the common themes noted in this response were associated with reasons why they were not creative. By comparison common themes from those participants that stated they were creative are more commonly related to reasons they *were* creative. Within Table 1, the codes are also grouped into similar themes across the "creative" and "not creative" columns. For example, the "original ideas" code is in the same row as the "not original ideas" code. In some cases, there were codes associated with the "creative" response including "domain of expertise" and "problem solving experience" but no related codes associated with the "not creative" responses.

Table 1. Common creativity-focused themes from follow up interviews of student participants

Creative *(i.e. reasons why the person, their methods, and/or their ideas ARE creative)*	**Not Creative** *(i.e. reasons why the person, their methods, and/or their ideas are NOT creative)*
Ideas (are creative/not creative)	
Ideas are not based on previous solutions/existing ideas: Their ideas are not from or specifically related to the previous solutions/existing ideas **Combining existing and new ideas:** The ideas developed use prior solutions developed by others combined with their own ideas and adaptations	**Previously implemented (other people's) ideas:** They have implemented ideas selected from the library of resources and they are now repeating what they have done before. **Previously seen (other people's) ideas:** The ideas they are using they have seen before but have not used/implemented before.
Original ideas: The ideas they develop no one has thought before	**Not original ideas:** The ideas they generated are not original; they are not able to come up with ideas on their own.
Ideas that are outside of the box: Their ideas/solutions are extravagant	**Safety/risk-averse ideas:** They choose solutions that are not risky; they are thinking about safety and risk when designing solutions **Efficient/practical ideas:** They develop realistic solutions that could easily be applied/economical and avoid waste **Simple ideas:** Their idea(s) is simple and straightforward.
Methods (are creative/not creative)	
Approach problems from a different angle: The method they follow to develop the solution is unique/they think from other perspectives	
Themselves (participant is creative/not creative)	
Domain of expertise: They make creative solutions based on knowledge and experiences gained in the past that are that specific field (i.e. the same domain as the problem) **Problem solving experience:** They have skills and/or know methods they can apply to solve any problem even if not in their domain of expertise	
Have multiple ideas: They are creative because they are able to come up with multiple approaches to solve the problem	**Not having multiple ideas:** They are not creative because they are not able to generate more than one/many alternate solutions/ alternatives

Results and Discussion

Self-Rated Creativity vs. Measured Creativity

Students, on average, self-rated their creativity as a 6.4 (median 7). This was similar to but slightly higher than practitioners at 5.9 (median 6), and similar to faculty at an average of 7 (median 7). Similarly, the overall creativity score based on the results of the K-DOCS survey suggest that in general the range of creativity scores of undergraduate students, academic faculty, and practicing engineers are similar across roles. Students K-DOCS-based creativity score (overall) was 6.0, practicing engineers' was 6.0 and faculty's was 6.1.

Interestingly, perception of creativity compared to participant's creativity score is overvalued (higher than K-DOCS creativity score) amongst undergraduate students and academic faculty (with the academic faculty overvaluing the most) and undervalued (lower than creativity score) amongst practicing engineers. This suggests that role-based factors and experiences may influence perceptions of creativity. Subcategories within the creativity score survey also indicate two areas of difference amongst roles, these being a higher creativity score in faculty amongst scholarly creativity and a higher creativity score in practicing engineers amongst artistic creativity. The next section discussed the reasons participants cited for being or not being creative.

Variation in Definition of Creativity

When completing analysis of the existing data on self-rated creativity scores, we found that some participants have different definitions of what a "creative person" means. Since participants were not explicitly asked to define creativity as an interview question, not all participants had answers mentioning defining this in their own words. Among 37 undergraduate participants, 13 offered responses. The following are some of these responses.

Most student participants that stated a definition defined a creative person as being "*able to come up with (many) original ideas."* Two participants viewed creative as someone different than themselves, specifically someone who is able to "*throw any crazy idea around*" or "*throw stuff at the wall and see what sticks*." Some student participants suggested how a creative person would make their solution more creative. As one participant shared, they would *"spend more time thinking of other solutions or maybe how to alter or change this one*." and another participant said they would "*take a lot of different factors into account and try out a couple of different ways before… settl[ing] on one choice*."

Rationale for being Creative or NOT Creative

As noted in Table 1, common reasons participants (students) cited for a *lower* self-rated creativity score (i.e. "not creative") related either to the participants' seeming inferiority of their ideas, or themselves. Regarding ideas, participants felt their ideas were (a) too simple/straightforward, (b) were previously used by others, (c) were previously implemented by them, or (d) were not "original". They also stated that external influences impacted the creativity of their ideas, namely (e) safety/risk, and (f) economic/practical factors. Regarding themselves as being inferior (i.e. "not creative"), participants cited (a) not being able to come up with new ideas on their own, (b) not being able to come up with multiple ideas.

Among students, the common reasons students stated as the reasons for self-rating their creativity as high included "*have multiple idea*s", "*approaching problems from a different angle*", and having "*original ideas*". As an example, for *have multiple ideas,* one student stated, "*I thought a bunch of ideas for the first five, ten minutes.*" Another stated "*I like to list a bunch of solutions and list their pros and cons*." For approaching problems from a different angle, one student stated they like to "*find new ways to do things and improve on things*"; another explained "*I might get a lot of different options and look at alternative ways to do stuff*." For *original ideas* one student stated, "*I think creativity is everything about coming up with original ideas*."

Common reasons for participants cited as having a *higher* self-rated creativity score (i.e. "creative") related to ideas, methods or themselves. For ideas, participants stated their ideas were (a) not based on existing solutions, (b) are original ideas, (c) are ideas that are "outside the box", and (d) combine existing and new ideas together. For themselves, participants stated themselves (a) having many ideas/able to produce multiple solutions, (b) having problem solving experience, or (c) having domain expertise in the area of the problem enabling them to develop creative solutions. For methods, participants identified (a) following a method that allows them to approach a problem from an alternative angle.

The most common reason students cited not being creative included themes associated with their ideas: "*efficient/practical ideas*", "*previously seen ideas*", and ideas that were "*not original*". As an example, for efficient/practical ideas, one student stated, "*I am realistic and I try to create things that will work physically*". For "previously seen ideas", one student explained "I come up with something that I'd seen before" and similarly "I got a lot of my ideas from things I've seen." For original ideas, as another senior student stated, "*If you're creative enough to come up with multiple solutions, they would all be different and you could figure out which one's best*." Students also highlighted the importance of coming up with ideas that are original, as one junior student stated, they were not able to "*come up with something that is totally new*."

As seen in the themes above, the most common types of reasons participants stated they were/were not creative related to the characteristics of the ideas they generate, and to a lesser extent, their methods or their abilities.

Two Themes that were Less of a Focus for Students than Faculty and/or Practitioners: Domain of Expertise and Safety/Risk

The common themes discussed above point, such as "*have multiple idea*s", "*approaching problems from a different angle*", and having "*original ideas*" to what students appear to be thinking about in regards to creativity. What is perhaps most notable, however, is what is NOT present in terms of reasons students cite for being or not being creative in their problem solving process. As discussed in prior work [7], practitioners cited the ability to be creative if the topic of the problem was within their domain of expertise. More specifically one stated "*I would say I can be creative but it has to be in my wheelhouse of expertise*", and another stated, "*If I have the past experience on the problem I'm dealing, I can be absolutely creative*." Students likely have a more limited domain of expertise in a certain area preventing them from having the level of experience of a practicing engineer.

Faculty and practitioners also discussed safety and risk related concerns, for example one stated "*it's got to be tried and true*" in order to proceed with a project idea; another similarly explained "*You can be as creative as you want but your solutions may not work or practically implemented. You need practical knowledge about what works and what will not wor*k." Similarly, a faculty member explained that "*you need creativity and practical knowledge about what will work and what will not work*". Students, similarly in some cases, mentioned concerns over practicality, however the only student that mentioned risk stated that this was important because they were "*taught in civil engineering, to kind of be safe more than being innovativ*e." The phrasing of this suggests, at least for this student, that they understood the idea of needing to be "safe" when developing a solution, but they relate this only to what they were told in class, rather than something experienced themselves. This student was also a senior; no freshman, sophomore or juniors mentioned safety-related concerns.

Our prior research suggested that practitioners may feel restricted by unspoken expectations, especially that they are expected to develop working, practical solutions with specific design constraints. It was also found that practitioners with more field experiences tend to consider safety-related concerns and more practical solutions when designing solutions, but they also suggest this factor hinders the exploration of creativity in problem solving. One related study found "Safe-by-Design is highlighted in a large number of engineering disciplines and safety is an important value in any engineering design" [8]. This paper also highlighted the importance of considering risks when designing engineering solutions by asking questions such as: *What could go wrong with this design in its intended or unintended use? Which components and structures are potentially dangerous? How can the design be adapted to prevent the occurrence of risks, for instance, by replacing, changing, or reducing components? If things do go wrong, how can adverse effects be prevented or controlled?* Overall, this suggests that practitioners and faculty have a more internalized understanding of the importance of risk and safety in developing engineering solutions than engineering students. This also suggests, however, that practitioners and faculty feel their creativity is influenced by these externalities. Students, however, appear to think some about practicality but less about safety and risk factors (with the exception of one senior student expressing concern about this as learned from their class).

According to our recent published paper that collected data from faculty members and practitioners [7], faculty and professionals shared concerns that creative ideas are often not realistic, and cannot be achieved. One practitioner states, "*I guess completely creative…would not be most likely achievable*." With the question of if concerns with safety will increase as college students gain more experiences in civil engineering, we compare responses coded under safety, practical and realistic solutions. Data suggests that faculty members and practitioners with more experience in developing and implementing engineering related domains of knowledge feel more confident in providing solutions, and in some cases creative solutions in solving ill-structured problems. They are also the ones implementing engineering design concepts that consider risks by presenting solutions that are "*economical, effective, and will physically work*."

While more work is needed in this area to better understand how the idea of risk/safety and creative solutions interplay within the civil engineering space, analysis of this data from follow up interviews suggests that perhaps students may be more creative initially and not consider concerns of safety and risk, then when transitioning into practice, they may be more risk-averse because they have more understanding of the concerns of safety and risk, but limited field experience as a practitioner. Then, upon working in the field for a while, they may be able to develop more creative solutions that also will work because they can combine both field experience and creativity. Given that the field of civil engineering and the resulting designs implemented by civil engineers have a significant impact on many people, and the quality of these designs is imperative to ensuring public safety, it is no wonder than the concepts of creativity and risk are seemingly at odds.

Conclusions, Limitations, and Future Work

Engineers, like many other professionals, will collaborate on projects. Further, they will likely plan and manage their timelines when working on projects. For this study, each participant independently solved an ill-structured problem with the presented resources under a limited time constraint. Several participants shared during the follow-up interview that they wished more time was given to develop creative solutions or wished they could collaborate with others or refer to external resources. While the data collection approach may not accurately portray the working environment of engineers, the data collected still provide insight into creativity in relation to the solving of ill-structured problems.

Overall, this research study demonstrates there are common themes used by students to describe their creativity, and these themes are typically associated with their ideas, their methods of solving problems, and/or themselves (the participants). Students appear to rate themselves similarly to that of faculty and practicing engineers, and slightly overrate their overall creativity, as compared to practicing engineers who underrate this. Students also appear to think less about safety and risk related factors in developing solutions to ill-structured problems, as compared to faculty and practicing engineers. Future work is needed to better understand the interplay between creativity and domain knowledge and experience, as civil engineering students progress from students to practicing engineers. This may help point to how to best support creativity and creative solutions in civil engineering while still resulting in solutions that ensure the safety of the people they serve.

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