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RUI: Understanding How Engineers Draw from their Knowledge and Experience to Solve Design Problems Creatively

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Abstract

Engineers regularly face problems and must draw from past experiences to solve them. The more experiences a person has, the more ideas he or she is able to develop. Further, engineers with different experiences may develop different types of ideas. This research aims to develop a way to measure the experiences of a designer in order to predict his or her ability to generate creative solutions to a problem. This new understanding of the creative process will enable teachers to understand how engineers gain experience and use that experience to generate high-quality ideas, improving the ability of educators in the United States to teach creativity and innovation in the classroom. This research will also provide a way for individuals to understand their own strengths in creative thinking and ways in which they can become more innovative. Finally, this research will enable project managers to strategically create diverse teams of problem-solvers to maximize the types and quality of ideas developed in a team's problem-solving process.

Research

This research will measure an aspect of individual creativity, spontaneous flexibility, from a psychology perspective and an engineering design perspective. The psychology perspective focuses on an individual's experience and problem-finding ability, while the engineering design perspective focuses on the individual's problem-solving ability. Statistical correlations between these two perspectives will provide insights into the value of an individual's problem-finding ability when faced with problem-solving tasks. It is hypothesized that when individuals perform these problem-finding or problem-solving tasks, they draw from the same cognitive network of relationships between artifact functions and forms. A cognitive model will be developed to bridge the gap between psychologists' view of spontaneous flexibility and applications in engineering design and to isolate the role spontaneous flexibility serves to enhance problem-solving tasks often encountered in engineering design. Spontaneous flexibility will be measured multiple times from both the psychology and design perspectives, providing repeated measures of the individual's spontaneous flexibility. This experiment design and the rigorous data analysis techniques will enable a large portion of the statistical variability to be accounted for, providing new insights and applications of the role spontaneous flexibility serves in engineering design. Statistical analyses of a longitudinal study of engineering students and demographic information will provide an understanding of how students grow in their creativity throughout the engineering curriculum and how students' backgrounds and experiences are related to their spontaneous flexibility.

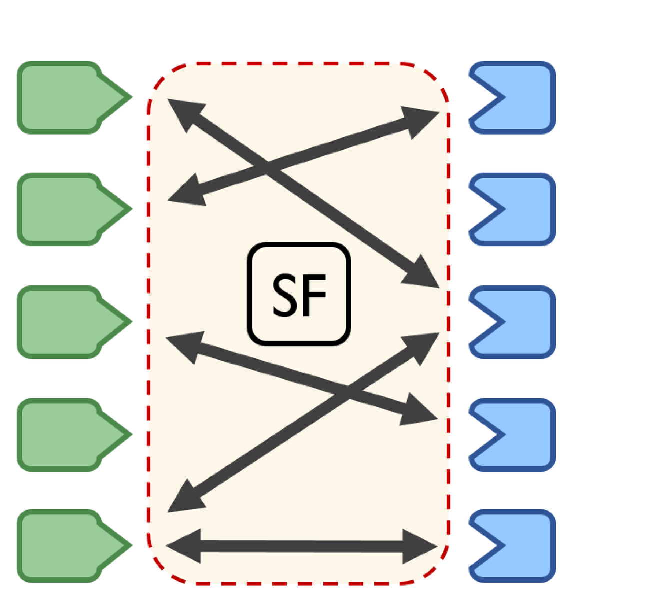

Figure 1: Spontaneous Flexibility Cognitive Model

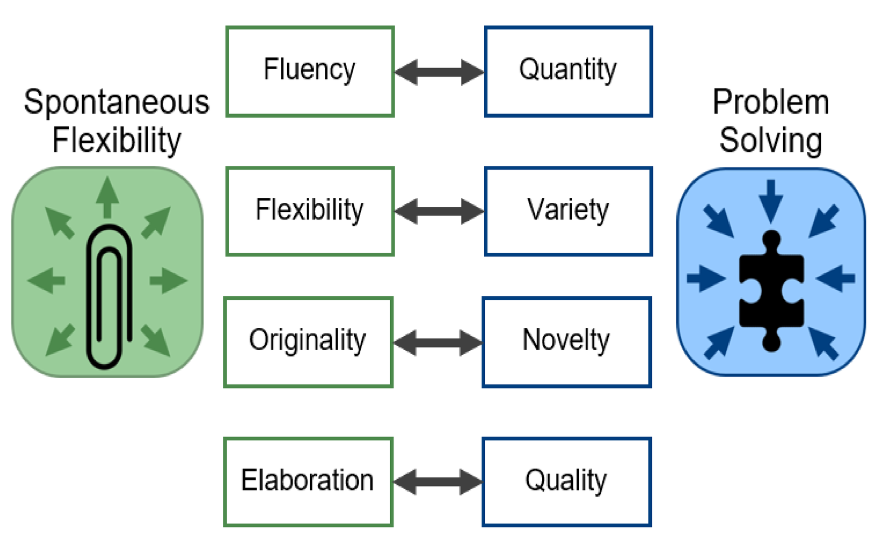

Figure 2: Problem Finding Task and Problem Solving Task Metrics

Research Questions

Spontaneous Flexibility (SF) is the ability of an individual to generate different and appropriate responses to a given situation [1].

1. **What is the value of spontaneous flexibility in engineering design?**
   a) Does SF improve ideation?
   b) Is a high SF always effective for design?
   c) Is an effective designer one who can identify when SF is most appropriate?
   d) What role do requirements (implicit or explicit) play in SF?
2. **In what ways do engineering students learn spontaneous flexibility, and how can spontaneous flexibility be improved?**
   a) How can an engineer's cognitive function-form network be expanded?
   b) Can engineers learn to access their function-form network more effectively?
   c) Is SF learned in engineering courses?
   d) In what types of courses is SF learned?
   e) How do diversity factors of gender, ethnicity, and culture shape the cognitive function-form network engineers build?
3. **How can individuals' spontaneous flexibility be leveraged to improve engineering design?**
   a) What is the relationship between an individual's background and his or her SF?
   b) How does an individual's SF contribute to the team's SF?
   c) How can understanding an individual's background reveal opportunities to improve his or her SF?

Preliminary Findings

Overview of Spontaneous Flexibility Test

The SF test is made up of two tasks, a problem finding task (FT) and a problem solving task (ST). Each task has three separate prompts for the participant. In the FT, the participant is asked to list different uses for an object. In the ST, the participant is presented with an open-ended design problem and asked for a list of solutions.

Quantity Scoring Results: FT vs. ST

The normalized FT and ST quantity of responses for each participant are plotted in Figure 3. As seen in the figure, there is a positive correlation between participants' scores on the FT and ST ($r=0.75$, $p<0.0001$, $n=52$). This result is expected because the tests both require divergent thought processes.

Variety Scoring Results: FT vs. ST

The normalized FT and ST variety scores for each participant are plotted in Figure 4. There is a positive correlation between participants' scores on the FT and ST ($r=0.65$, $p<0.0001$, $n=52$). The significance of this relationship is surprising because the flexibility demonstrated in each test is different. Flexibility in the FT requires the participant to be flexible in the way he or she understands a given object, while flexibility in the ST requires the participant to be flexible in the way he or she addresses a problem. This indicates that participants who can think of an object in many different ways can also think of a problem in many different ways, potentially leading to a very creative individual.

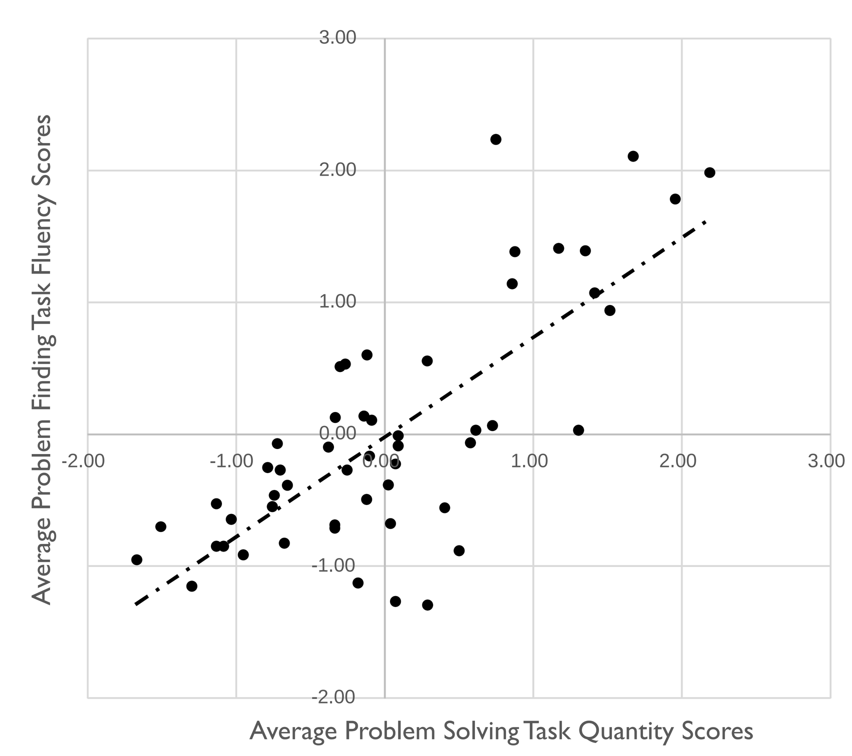

Figure 3: FT Fluency vs. ST Quantity Correlation

Figure 4: FT Flexibility vs. ST Variety Correlation

Spontaneous Flexibility Evaluation Methods

Quantity is a measure of a participant's ability to ideate quickly and is useful to measure because it has been correlated to creative potential. A participant's quantity score is the sum of his or her valid responses.

Variety is a measure of a participant's breadth of concepts. Preliminary analysis calculated the participant's variety score as the number of first-level branches covered in a genealogy tree of possible responses (see green boxes in Figure 5 below). Additional variety metrics are currently being explored [2]

Novelty is a measure of how unexpected or unusual a participant's idea is compared to the set. Novelty is measured by weighting each level of the genealogy tree (see Figure 5) and combining these weighting factors with the number of participants listing them [2,3].

Quality is measured using Seepersad's feasibility metric, in which each idea is scored on a scale from 0-10 based on its physical impossibility, technical difficulty, or its use as an existing solution. [4]. This method aimed at capturing how effectively and feasibly each idea meets the design requirements, based on Shah's work [2].

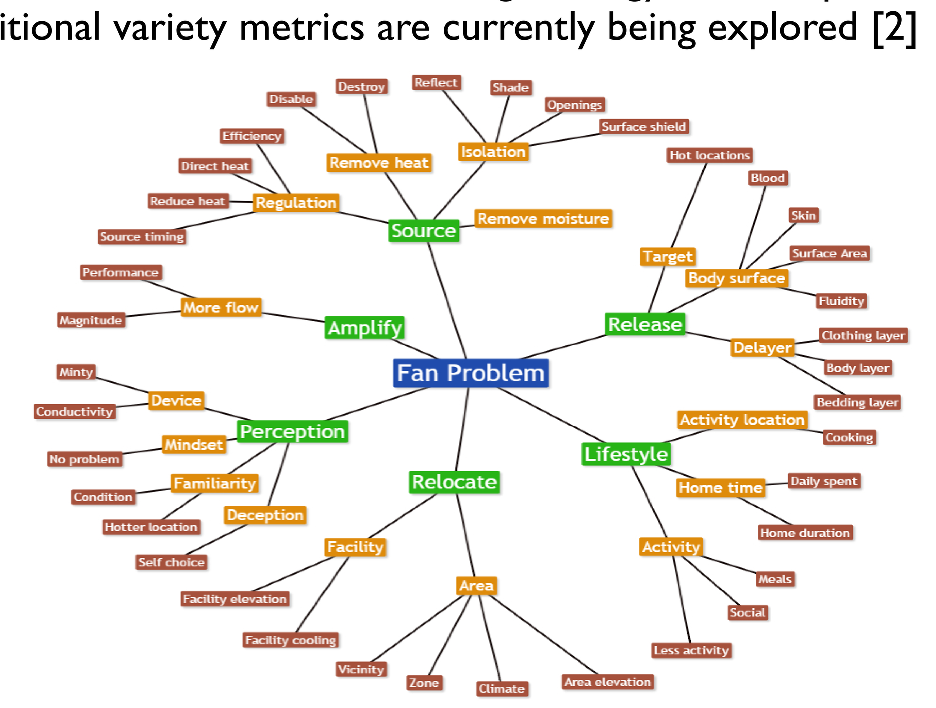

Figure 5: Sample Genealogy Tree (subset)

Acknowledgments

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