RFE: Trust but Verify: The Use of Intuition in Engineering Problem Solving - as Captured through Cognitive Task Analysis

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Intuition is recognized as a defining quality of experts and used by professionals in specialized fields such as nursing, management, law, engineering, and a range of other STEM fields [1-4]. Developing expertise [5, 6] and intuition [7, 8] both require experience, resulting in their co-development. Within engineering, intuition is defined as the expert's ability to leverage past experience to subconsciously assess a solution or predict an outcome and is often used by engineering practitioners when they are under pressure from constraints (e.g., lack of time) [7]. Practicing engineers rely on engineering intuition to solve problems, but intuition use is often discouraged in undergraduate education [7]. This gap between professional practice and educational norms limits our ability to prepare the future engineering workforce and demonstrates our limited understanding of engineering intuition. In this Research in the Formation of Engineers (RFE) grant, we build on previous work that defined engineering intuition to investigate how engineering practitioners apply intuition and work towards narrowing the gap between problem solving in engineering practice and education. We have focused our work on two specific research questions:

> RQ1: How does the application of intuition manifest in engineering problem solving?
> RQ2: How does prior engineering experience influence the application of intuition when approaching engineering problems?

Theoretical Grounding and Relevant Literature

This work is grounded in the expertise development literature as well as recent advancements in engineering intuition research. In expertise development, experience results in increased efficiency [9], skill acquisition [5, 10-12], and proficiency [13, 14]. Intuition is recognized as an essential characteristic that defines the expert and is linked to information processing [15], response speed and automaticity [16], and information storage [17].

Engineering intuition is specifically framed as an expert problem-solving skill that is triggered by a problem's existent constraints [7]. This framing as an expert skill specifically is supported by known differences in how novice and experts approach problem solving [18, 19]. Experts have a larger working memory allowing for greater information storage and processing capacity [20]. This increased processing capacity allows experts to approach problem-solving decisions in a reactionary or intuitive, rather than systematic, way [21]. Although these abilities are assumed to develop during formal education, they appear to arise primarily through professional experience [7].

Intuition's subconscious nature is among the factors that make it challenging to study. The recent definition and supporting Leveraging Intuition Towards Engineering Solutions (LITES) framework on engineering intuition [7] provide theoretical grounding for how to identify intuition without its explicit mention. LITES details how intuition is an amalgamation of problem-solving approaches rooted in prior knowledge and experience that manifests as a physiological sense when an expert (experienced) problem solver is confronted with a constraint. Intuition engages subconsciously, but whether to use the intuitive answer or solution can be either a conscious or subconscious decision. Problem-solving approaches, specifically identified as part of intuition, include taking a big picture view, assessing reasonability, predicting possible outcomes or consequences, and leveraging data. Identifying elements of LITES in expert problem solving offers a possible route for identifying the use of intuition despite its subconscious nature, as we aim to do in this work.

Research Design

We are using Cognitive Task Analysis (CTA), a methodology with a strong record of use in social science studies of expert performance [22], to investigate our research questions. Our interview protocol follows the best practice of mixing CTA techniques to allow for robust data collection [23] with target populations of mid-career engineers (5-10 years of experience) and new engineers (0-1 years of experience). We use three CTA techniques: 1) Simulation Interviews, 2) Critical Decision Method, and 3) Knowledge Audit. Simulation Interviews observe a participant "thinking-aloud" while they solve a problem or complete a task. The Critical Decision Method entails the interviewer and participant creating a timeline of problem-solving decision points through a series of four interview "sweeps" or stages. The Knowledge Audit Method provides additional probing questions that elicit the knowledge or skills that were used while navigating the decision points. To date, we have used convenience sampling for preliminary pilot interviews with three participants outside our target population with 10+ years of industry experience [24] that showed the viability of our protocol using the Critical Decision Method and Knowledge Audit Method. Our second series of pilot interviews is with our target population. We have interviewed four mid-career engineers with the same preliminary protocol and five new engineers with a new protocol that begins with a Simulation Interview.

Ongoing Methods Development and Initial Pilot Results

Our initial research plan included investigating differences in problem solving by experience level through the use of "well" and "ill" structured problems through Simulation Interviews. Ill-structured problems have no clear correct answer or path forward and have greater similarities to problems that professional engineers are often faced with; they are also called complex, open-ended, ill-defined, non-routine, and wicked [25-28]. Well-structured problems are easier to manage in the classroom. Our intention was to design a single problem of each type that could be used across all participants for comparison of how and when intuition was used, if at all, across the problem types and experience levels.

Designing problems that fit the necessary criteria (both specific enough to participant's expertise to trigger intuition, but broad enough to be used for different participants) proved to be a challenging and ultimately infeasible task. We modified our approach through consultation with our advisory board and shifted our objective away from the difference between well- and ill-structured problems. Our new approach focuses on the difference between how mid-career and new engineers approach solving real engineering problems through what we are calling paired-problem interviews.

Paired-problem interviews begin by interviewing mid-career engineers about an ill-structured problem that they solved at work in the recent past. This approach is similar to our previously described initial interviews of experts with 10+ years of experience [24] where we only use the Critical Decision Method and Knowledge Audit Method. We then use the problems from the mid-career engineer as the basis for the Simulation Interview. This Simulation Interview then serves as the context for the Critical Decision Method and Knowledge Audit Method interview that immediately follows. If the new engineer is on a similar career trajectory to the mid-career engineer, we consider the paired interview a "high-match pair." Alternatively, a "low-match pair" is one where the new engineer is a new practitioner on a different trajectory or a senior undergraduate student with limited industry experience.

To create the Simulation Interview problem for the new engineer, the problem described by the mid-career engineer is de-identified and turned into a "choose your own adventure style" simulated problem. Decisions made by the interviewee change the direction of the problem in real time and affect the final (simulated) outcome. New engineers are given a bare-bones prompt of the problem with the ultimate goal at the beginning, and asked "what would you do first?" Information about the problem is revealed in real time as they make decisions. For example, their problem may center around an equipment failure that is a known issue to the vendor, but that information is not shared unless they say they would reach out to the vendor. The problem also includes "surprises" such as a supplier calling "scope-creep" that pivots the problem in a different direction. These surprises are based on what happened to the mid-career engineer. Overall, these interviews can last up to two hours, so we aim to keep the simulation portion of the interview to 20 minutes. We start offering additional information while being careful not to direct them one way or another if we find that the participant is not making forward progress.

We have completed five paired-problem interviews with four unique problems; one we characterize as a high-match pair and four we characterize as a low-match pairs. We were able to readily respond to the actions or inquiries of the new engineer in the high-match pair based on what we knew from the mid-career engineer. Here the new engineer demonstrated similar problem-solving strategies to the mid-career engineer.

In our low-match pairings, students implemented problem-solving strategies that made consistent progress toward a solution within the 20-minute time limit. We noticed that students required periodic prompting to move them to making a decision. Each student was also observed to have made different underlying assumptions in interpreting the problem statement. In some cases, incorrect assumptions led us to revise the problem statement for clarity. Students in the low-match grouping spent more time making their decisions compared to the student in the high-matched pair. We attribute this result to the low-match students' lack of first-hand familiarity with the scenario. The low-matched students also veered further away from the original scenario. For example, after discovering new information about a supplier, a low-matched student decided to end the project proposal rather than accept the higher risk associated with the new information.

Next steps

Data analysis is ongoing for the five paired pilot interviews. Finding a high-matched pair is more challenging than initially expected particularly with our population constraint of less than one year in industry. We plan to continue to search for high-match pairs to see if simulation interviews progress similarly to our current high-matched pair. In parallel, we plan to continue developing simulation problems through additional mid-career interviews (problem generation) and new career engineers (problem testing).

Broader Impacts

Although intuition is a significant skill in expertise development, it is often perceived as secondary to data-driven reasoning in engineering problem solving. Findings from this work aim to create a foundation for the application of intuition in engineering problem solving to: 1) bridge the disconnect between classroom and real-world engineering practices, 2) inform the design of educational interventions that promote intuition development, and 3) provide an understanding of how early intuition development can help level the playing field for all students regardless of individual background. We hope to reduce the dependence of intuition development on co- or extra-curricular experiences that may not be equally available to all students [29-31]. Intuition development leads to expertise development which in turn promotes metacognition [21]. An increase in metacognition can result in expertise development [32] and improved problem-solving approaches [33], which directly benefits students from underrepresented groups whose expertise is more frequently discounted or dismissed [34, 35]. Intuition development is also linked to confidence [7, 36, 37]. Increased confidence can reduce student attrition [38-40], which disproportionately affects underrepresented groups. Focusing on intuition development can serve as a means for boosting student confidence and expertise, ultimately supporting greater retention and workforce development.

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