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Using Cognitive Task Analysis to Observe the Use of Intuition in Engineering Problem Solving

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Motivation and Background

This work-in-progress paper discusses ongoing efforts to examine how engineers use intuition in problem solving. Engineering intuition, defined as "the ability to leverage past experience to efficiently assess the present and predict the future" (Miskioğlu et. al., 2023), is a problem-solving tool used by practitioners when faced with pressure from constraints such as limited time or resources. Intuition broadly is developed through experience and used by individuals with a high level of domain expertise to solve problems and make decisions within that domain (Dreyfus & Dreyfus, 1980), making it of great interest in engineering problem solving. The overarching goal of this research project is to characterize how intuition emerges in problem solving across new (zero to one years of experience) and mid-career (six to ten years of experience) engineering practitioners. Additionally, we seek to identify how the application of intuition varies when approaching "ill" versus "well" structured engineering problems and the effects of problem-expertise domain alignment. Well-structured problems are typically characterized by having a lower complexity as compared to ill-structured problems (Greeno, 1978; Mayer & Wittrock, 1996; Reed,2016). Well-structured problems have criteria for testing the proposed solution and a mechanized process for applying criterion (Simon, 1973). Alternatively, ill-structured problems are considered more complex, open-ended, non-routine and ill-defined (Coyne, 2005; Lock, 1990; Lönngren, 2017; Mayer & Wittrock, 1996). These problems are typically more vague in their goals and have no definite process for how to solve them (Simon, 1973), such as engineering design problems.

In this paper, we share our initial efforts in developing the methods to pursue this research. We are using Cognitive Task Analysis (CTA), to our knowledge a new method in engineering education, to examine the use of intuition in engineering problem solving. CTA is a class of observational protocols that surface tacit knowledge through engaging experts with a task (Crandall, 2006). The purpose of CTA is to capture how the mind works through three primary aspects: knowledge elicitation, data analysis, and knowledge representation. Many methods of CTA exist, and best practices call for a combination of CTA methods. In this study we are using two methods: 1) the Critical Decision Method (CDM), which assesses individuals decision making in non-routine incidents through a set of cognitive probes (Klein, 1989), and 2) the Knowledge Audit Method (KAM), which we use to guide our probing questions and identify types of knowledge used, or not used, by the participant during the non-routine incident (Crandall et. al., 2006).

We chose CDM for our interviews because this method is used to study cognitive judgment and how individuals with varying levels of expertise make decisions in their career (Klein, 1989). CDM has been previously used to elicit knowledge from urban and wildland fireground commanders, tank platoon leaders, structural engineers, design engineers, paramedics, and computer programmers (Klein, 1989). A key feature of the CDM protocol is the co-creation of data between the interviewer and the participant through the development of an incident timeline that identifies critical decisions. This timeline is initially drafted by the interviewer in real-time and shared with the participant, at which point the participant adds modifications before the interview proceeds.

Complementing the CDM method with KAM provides further structure to our interview through a set of probes that elicit aspects of one's knowledge and skill regarding specific tasks (Crandall et. al., 2006). This pairing allows us to better understand the role of expertise in solving the problem at hand. KAM probes posed during the interview are based on specific cognitive elements that are characteristic experts in a certain knowledge domain. KAM probes are organized into eight dimensions, which include 1) past and future, 2) big picture, 3) noticing, 4) job smarts, 5) improvising/spotting opportunities, 6) self monitoring, 7) anomalies, and 8) equipment difficulties (Crandall et. al., 2006). The role of probes within these dimensions is to elicit and collect examples in order to identify skills, patterns, and strategies used by experts in specific situations (Crandall et. al., 2006).

The focus of this paper is the ongoing initial pilot phase during which we developed, and are testing and modifying our CTA protocols.

Methods

Pilot study participants are being recruited through convenience sampling with the inclusion criteria of having at least ten years of experience in engineering. We chose this experienced sample as they are most likely to use intuition in problem solving, and therefore most appropriate for assessing whether we can observe the emergent use of intuition through the CTA protocol.

Interviews are conducted over Zoom and recorded with at least two interviewers present. The primary interviewer leads the questioning while the secondary interviewer takes notes, asks additional questions when appropriate, and creates the timeline that is part of the CDM protocol. This role of the secondary interviewer has proved to be essential, as the CTA protocol is both lengthy and cognitively taxing for the primary interviewer. Our first attempts at using the protocol quickly revealed that it is difficult for one person to lead the interview, take notes, choose the appropriate paths, and create the timeline that is part of CDM all at once.

The CDM protocol involves four sweeps, 1) identifying and selecting an appropriate incident to discuss, 2) creating a timeline of the events in the incident, 3) sharing the timeline with the participant and using probes to deepen understanding of co-identified decision points, and 4) hypothetical queries and differences between experts and novices. CDM is well-suited to help us discover differences in problem solving across experience and problem types as it requires participants to deeply discuss and analyze how they approach solving problems.

In the first sweep (identify an appropriate incident), participants in the pilot are asked to come to the interview having thought of a challenging problem they solved in their career. The interviewers then determine whether the problem is appropriate by assessing if the participant had a direct "doer/decision maker" role in solving the problem (Crandall et al., 2006). For example, a participant who was the lead engineer for a project and spoke about a problem where they had to make major tradeoff decisions between cost, schedule, and technical requirements would be appropriate. However, the same incident with a junior engineer as the participant simply observing the lead engineer make design decisions would not be appropriate. During this first sweep, the interviewers also ensure that the problem involves a critical decision that has a direct impact on the outcome, rather than just an unusual or dramatic event that does not involve the participant's decision making. As the participant summarizes the event sequence, the interviewers listen for turning points and meaningful distinctions in the event sequence. These distinctions provide the overall structure to probe for further detail in subsequent sweeps. Sweep one ends once an appropriate problem is identified.

In sweep two (incident timeline), the secondary interviewer creates the first version of the timeline while the primary interviewer asks questions on the problem-solving process. The primary interviewer asks about problem outcomes while the secondary interviewer adds the outcomes to the timeline. The primary interviewer then summarizes the outcome to confirm with the participant. At the conclusion of sweep two, a preliminary timeline is created but not yet shared with the participant.

At the start of the third sweep (deepening probes), the interviewers share the preliminary timeline with the participant to identify any gaps and add further details (Crandall et al., 2006). The interviewer and the participant together highlight the decision points made by the participant. CDM calls for probing deeper into all decision points during sweep three. However, because of time constraints and the threat of interview fatigue, we have the participant rank their decisions by perceived impact on the problem solution and proceed with the top ranked one or two. The probing questions used to uncover the processes involved in these critical decisions fall across eleven categories, 1) cues, 2) information, 3) analogs, 4) standard operating procedures, 5) goals and priorities, 6) options, 7) experience, 8) assessment, 9) mental models, 10) decision making, and 11) guidance, without introducing new information or leading the participant (Crandall et al., 2006). For example, an information probing question could be "What *information* did you use in deciding on aluminum rather than steel or composite materials?" A question on goals and priorities could be "What were the specific *goals and priorities* guiding your decision to reduce product testing in order to meet the schedule?" After applying these probing questions to the top-ranked decision point, the same types of questions are used to probe the second decision point if time allows.

The fourth and final sweep of CDM involves hypothetical queries and expert/novice differences. These questions are used to reveal even more aspects of the decision-making process that may not have emerged organically (Crandall et al., 2006). The questions in the fourth sweep are broadly divided into four categories, 1) expert-novice contrasts, 2) hypotheticals, 3) experience, and 4) aids. Question prompts include, "Would a novice have noticed the same cues you did in this situation?" or "How could additional training have offered an advantage here?"(Crandall et al., 2006). Some of the prompts are skipped if they were covered in earlier discussions on the problem.

At the conclusion of the CDM, the interviewers determine if enough information has been collected to satisfy the eight dimensions of KAM. Reflecting on the results of the interview so far, the interviewers determine which of these dimensions require additional probing that was not covered elsewhere in the interview. For example, when reflecting on the big picture, the interviewers could ask, "What are the major elements you have to know and keep track of?" which may be covered in sweep three of CDM. Again, the role of the second interviewer in note-taking and mapping emergent data to the KAM dimensions in real-time is critical to the success of the interview.

The interview closes with the participant recalling their relevant expertise and experience that guided decisions, providing feedback to improve the interview process itself if it was confusing (as this was a pilot), sharing any additional insights into drivers of their decision making that may not have already been covered, and consenting to potential follow-up contact during the analysis phase with clarification questions that may arise.

Pilot interview data is auto-transcribed via zoom, and after the transcript is checked the data is anonymized before analysis. Analysis consists of deductive coding (Salanda, 2021) of the interview by applying a previously developed codebook for engineering intuition (Miskioğlu et al., 2023). Application of this engineering intuition codebook allows us to discern whether our protocol has elicited themes associated with intuition and assess any modifications that should be made to the protocol. Each interview is coded by at least two members of the team, one who was present during the interview and one who was not.

Summary of Lessons Learned from Pilot to Date

Our pilot interviews to date confirm that CTA is an appropriate method for collecting rich data on engineers' approach to problem solving. We also recognize that our use of CTA with CDM and KAM is limited by participants' memory of the incident, their perception of the relative importance of the key decision points, and the practical limitation of not being able to probe every aspect of the incident. We accept the trade-off between these limitations and the benefits of CTA.

A key takeaway from our pilot work is the importance of a trained research team of at least two interviewers when conducting a CTA interview. The essential role of the secondary interviewer cannot be overemphasized, as it gives the primary interviewer the cognitive space to focus on conducting the interview. This need for at least two interviewers with sufficient CTA experience is also a limitation of the protocol. We have found that the time invested in becoming comfortable with a CTA protocol is greater than other qualitative methods. If a trained team member takes a leave of absence data collection may have to pause until they return.

In addition to the pilot interviews, we also benefited greatly from conducting "pre-pilots," where we simulated an interview using the protocol with trusted colleagues outside of our target sample population. In this simulated interview, we paused to discuss the purpose of each sweep and any awkward or unclear moments, and we learned how we need to organize ourselves to navigate the sweeps. For example, creating simple graphic organizers for real-time data documentation that allow us to quickly assess whether a sweep is complete, or the KAM dimensions are satisfied, was a key outcome of the "pre-pilot."

Anticipated Results and Significance

The overarching goal of this research is to provide a better understanding of engineering intuition and a foundation for the explicit application of intuition in engineering problem solving. More specifically, the initial pilot interviews support our ability to use CTA effectively in gathering high quality data that supports this research goal.

We anticipate this ongoing work will allow us to understand more about the role intuition plays in engineering. Ultimately, the differences in problem-solving approaches between new and mid-career engineering practitioners will illuminate how we approach teaching problem solving in undergraduate engineering education. This insight can help to restructure engineering education in a way that promotes expertise development and aligns with real-world applications of engineering (Metcalfe & Wiebe, 1987; Bolton, 2022; Bolton et. al., 2021; Miskioğlu et. al., 2023). In turn, this insight will be beneficial in onboarding new engineering hires in industry because students will graduate with more agility and adaptability in expertise development at their disposal. Overall, applying intuition in both academia and industry will benefit the engineering field by increasing the ability to creatively address society's greatest needs and challenges.

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