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Is it Rocket Science or Brain Science? Developing an Approach to Measure Engineering Intuition

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Introduction

Solving complex 21st century engineering problems requires an ability to judge the feasibility of solutions. This engineering judgement is an essential skill for today's engineering practitioners. It is imperative that we prepare the future engineering workforce to exercise this judgement, informed by engineering intuition, while avoiding graduates who simply take output at face value without critical analysis. This requires that we first understand the construct of engineering intuition.

This project seeks to characterize and develop measures of engineering intuition. Our work is structured into two initiatives guided by the following research questions:

Research Initiative 1: Characterizing Expert Engineering Intuition

RQ 1: What are practicing professional engineers' perceptions of discipline specific intuition and its use in the workplace?

RQ 2: Where does intuition manifest in expert engineer decision-making and problem-solving processes?

RQ 3: How does the motivation and identity of practicing professional engineers relate to discipline-specific intuition?

Research Initiative 2: Designing an Instrument to Measure Engineering Intuition

RQ 4: What would an instrument designed to validly and reliably measure engineering intuition look like?

Models of expertise development note intuition as a defining characteristic of the expert [1]. The notion of discipline-specific intuition has been explored in the fields of nursing [2] and management [3]. These explorations link intuition to the development of disciplinary expertise [4]. This literature is used to support the hypothesis that engineering intuition is an existent construct and may be defined as the ability to: 1) assess whether engineering solutions are feasible, and 2) predict outcomes and/or options within an engineering scenario [1].

We aim to answer our first three research questions using interviews with engineering practitioners at various stages in their careers, from five years of experience to retired. These interviews will provide insight into practitioner perceptions of engineering intuition and a basis to modify our hypothesized definition of engineering intuition (RQ 1), while identifying related constructs (RQ 2 and RQ 3). The emergent results will subsequently be leveraged to address our final research question. The ultimate goal of this project is to use our findings to develop classroom interventions that foster students' ability to develop, recognize, and improve their own engineering intuition.

Background

Intuition has been of interest in cognition and development of expertise for decades, but it continues to be a mysterious construct. Several academic models attempt to describe its relationship to the development of expertise. To date, these models have not provided a definition nor bridge the theory-to-practice gap of how to develop intuition. Our hypothesized definition considers intuition as a broad independent construct that is related to other constructs.

Definitions of expertise vary, but are typically identified by years of experience or accumulation of knowledge [5, 6]. Research in domain knowledge area indicates expertise can be: 1) developed through experience [7-10], 2) combined with a capacity to learn from both external and internal feedback [8], and 3) recognized by a strong capacity to form associations or run mental simulations [11]. Novices are conversely described as being at the beginning of their search for specialized knowledge within a domain [12, 13]. Novices and experts organize information and approach problems in different ways [14-16].

Expertise development is explained through several models that embed intuition as an important facet to developing disciplinary expertise. First, Patel and Groen [9] describe expertise as a progression along a novice to expert pathway through three distinct stages: 1) building content knowledge, 2) discriminating between relevant and irrelevant information when presented with a problem, and 3) efficiency. This progression to efficiency parallels the idea of intuition as a key characteristic of expertise development. Second, the Dreyfus Model [4] takes a more explicit approach proposing five-levels of skill acquisition: 1) novice, 2) competent, 3) proficient, 4) expert, and 5) master. A modified version of this model includes an "advanced beginner" before competent and instead ends with "expert" [17]. Intuition is explicitly recognized as an essential characteristic that individuals must depend almost entirely on when matriculating from proficiency to expertise in both versions of the Dreyfus model. Finally, Chi's model [10] (adapted from Hoffman [18]) suggests a proficiency scale: 1) naïve, 2) novice, 3) initiate, 4) apprentice, 5) journeyman, 6) expert, and 7) master. Chi explicitly notes that "experts cannot articulate their knowledge because much of their knowledge is tacit and their overt intuitions can be flawed (p. 24)." Only those who reach the level of master can begin to rely on their intuitions. These three models argue for the importance of intuition in developing disciplinary expertise, but do not define nor suggest how intuition may be developed [6, 7, 11, 12].

Research into discipline-specific intuition has been primarily conducted in nursing and business management. Benner's Stages of Clinical Competence [19] in nursing directly maps to the modified Dreyfus Model [17]. Expert nurses are described as having an "intuitive grasp" of situations and a complete view to accurately assess a patient and respond appropriately [20]. Intuition studies in nursing include grounded theory and phenomenological approaches, which have helped to legitimize the concept of intuition in nursing [2]. Trusting their intuition allows nurses to positively change the outcomes of their patients [21]. Intuition is often explained by nurses as an autopilot task that can be learned [22]. Business management studies have demonstrated that when business managers are missing information they make faster decisions and lean on their intuition [3, 23]. Executive managers state that intuition is as important as analysis when making decisions [24].

Intuition may also be connected to motivation and identity. Our previous work in the context of computer-aided problem-solving suggests that if a student's disciplinary identity does not match the problem or scenario they are asked to assess, they are less likely to demonstrate high intuition [25]. Accurate assessment of engineering solutions and scenarios requires additional effort that may be confounded with motivation. The effects of motivation on a number of student outcomes has been extensively studied [26-29]. Identity alignment has also been shown to be linked to professional motivation [30-33].

Nursing and business management are high-stakes and human-centered disciplines despite the differences they have in the nature of interaction and the consequences of poor decision-making. Literature in both disciplines imply the importance of discipline-specific intuition in decision-making and development of expertise. Characterization of discipline-specific intuition in engineering is still premature. A review of management literature on intuition in decision-making suggests integrating intuitive reasoning [34] into the engineering curriculum [35]. Gaps exist in how to define intuition and how to develop intuition across any of these disciplines. Our work is motivated by this gap and aims to characterize and eventually measure discipline-specific intuition in engineering.

This research consists of two research initiatives that will characterize engineering intuition and create a means of measuring intuition in the context of engineering.

Research Design

We are conducting a mixed-methods, multi-phase, research design to sequentially answer our research questions over the two-year span of our award (see Figure 1). Our methods leverage, expand, and build from the literature on expertise development and cognition as well as studies of related constructs and discipline-specific intuition. Components of the overall research design are broken up into two distinct *Research Initiatives* that target a subset of the research questions. Research Initiative 1 is designed to inform Research Initiative 2 to form a sequential explanatory design mixed methods research design [36].

Research Initiative 1: *Characterizing Expert Engineering Intuition*

The first initiative of this project builds on the presented theoretical grounding and studies in the fields of nursing and business management to characterize engineering intuition. We began with semi-structured interviews of six professionals from the fields of engineering, business management, and nursing. These three professions were chosen to represent our population of interest and professions with existing literature examining intuition. These interviews (Phase 0) were used to fine-tune our interview protocol and develop a preliminary codebook [37]. We subsequently interviewed 17 practicing engineers with 5-30+ years of experience (Phase 1). Participants were recruited through institutional alumni listservs and industrial advisory boards (IAB). Possible participants were screened to select a diverse cadre of participants for the study using a brief demographic survey, which included years of experience, gender, race/ethnicity, and industry of employment. An emergent thematic coding approach was used to analyze the interview data qualitatively [38, 39]; coding is still in progress. The qualitative analysis of coding and recoding is being used to identify themes that highlight factors and constructs related to engineering intuition. The final set of codes will be used to inform Research Initiative 2.

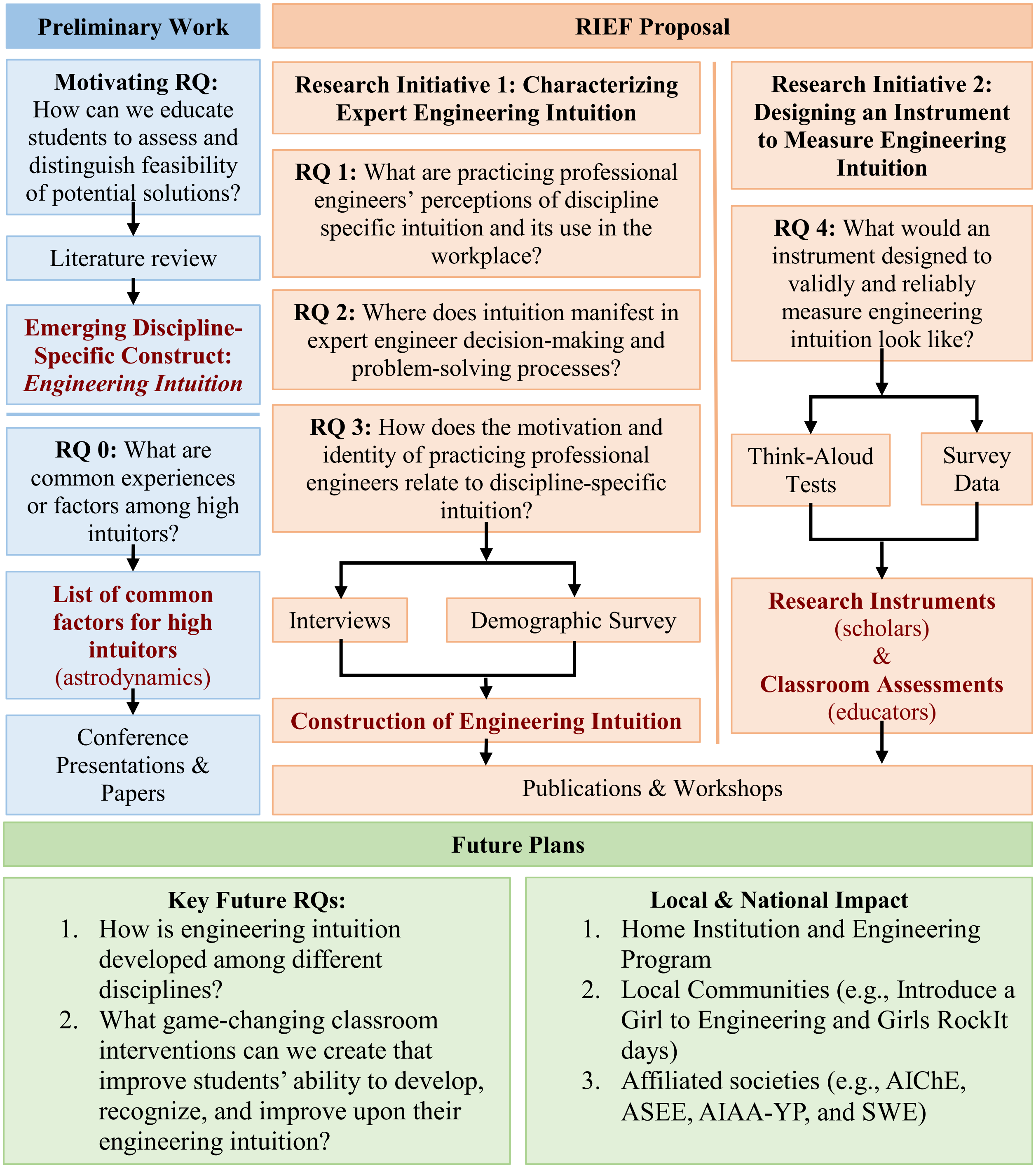

Figure 1: Visual mapping of research initiatives and embedded activities.

Research Initiative 2: Designing an Instrument to Measure Engineering Intuition

The next step of our project is to create an instrument capable of measuring engineering intuition (Phase 2). We envision a two-part instrument consisting of: 1) fixed, close-ended items (survey), and 2) open-ended engineering problem-solving challenge (engineering task). The emergent construction of intuition from Phase 1 will inform the direction for each part of the new instrument, including theoretically connected constructs.

The two parts – survey and engineering task – of the instrument will be developed in parallel making sure to collect validity evidence and address validity concerns throughout the entire process [40, 41]. Guidance from appropriate members of the advisory board and additional experts will be called upon to address content validity. A modified draft of the instrument will be shared with the team of experts allowing them to provide written feedback for each individual item. Face validity will also be addressed by conducting a usability test of potential users, i.e., engineering students. Students will be asked to participate in a think-aloud session in an attempt to capture in real time any confusion on items or any survey fatigue they may be experiencing [42, 43]. Think-aloud sessions will be observed by a member of the research team and documented using observational field notes [44]. Feedback obtained from both content experts and engineering students will inform revisions to the initial set of items prior to distribution and testing.

The engineering task will be based on questions from the Statics Concept Inventory [45, 46]. Statics questions were chosen because the subject is fundamental to mechanical, civil, and other related engineering fields. This computation will be followed with an “intuition check” question that asks the user to assess the confidence in their answer choice how they choose their answer, if they would go to their manager with just this prediction, and how they would justify their answer.

The resulting two-part instrument will then be distributed to collect responses that will be used for validity and reliability testing. The survey will be broadly disseminated to a diverse sample of undergraduate engineering students who are either enrolled in or have taken statics to explore the factor structure of the items and to test internal consistency. Survey dissemination is planned for Spring 2021; exploratory factor analysis and potentially confirmatory factor analysis are expected to be completed in the summer of 2021. Internal consistency will be determined by calculating Cronbach’s alpha. Additional correlational analyses will be calculated based on the sub-constructs ultimately included in the instrument. These calculations will provide additional construct validity.

Results and Discussion

Interview data of practicing engineers from Phase I are currently being analyzed and coded. Preliminary results indicate several themes exist across interviewee responses to questions pertaining to decision-making. One noteworthy standout in early coding processes is the role of constraints, particularly time. This early emergent theme connects to existing literature in decision-making and expertise. For example, Klein describes decision-making in time-sensitive environments as reactions, rather than choices [47]. We believe these reactions are engineering managers’ use of intuition. Managers report relying on their intuition when needing to make quick decisions on the job [23]. Novice managers are described as taking longer to identify key features of a case [3]. Time constraint was also an emergent theme in participant decision making processes during our Phase 0 study [37].

Conclusion and Future Plans

This project aims to characterize and ultimately measure the construct of engineering intuition Data collected from 17 interviews of practicing engineers with greater than five years of experience is currently being analyzed. Early coding suggests alignment with the existing literature on discipline-specific intuition, decision-making, and expertise, while offering direction in instrument design [37].

Our instrument to measure engineering intuition will leverage emergent themes from these interviews. We are currently working on the survey design with a question focused on statics concepts as the area of expertise. Our next steps are to test the survey prior to widespread deployment for data collection. The eventual goal of this instrument is to provide a tool for measuring engineering intuition that can support the development of engineering classroom interventions to improve intuition by providing a means to measure effect sizes.

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