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What Makes an Expert? Characterizing Perceptions of Expertise and Intuition Among Early-Career Engineers

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By

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Abstract

This thesis seeks to characterize if and how practicing engineers' perceptions of expertise development, decision-making processes, and engineering intuition vary by aspects of identity, specifically gender and career stage. This thesis is built from ongoing work of the Miskioğlu group on the relationship between expertise and intuition in engineering. Intuition is a characteristic of experts used in decision-making, and the importance of experience in the development of expertise is well documented in literature. There is a gap around how intuition relates to experience, prompting the need to compare the perceptions of early career engineers and mid-to-late career engineers. This thesis additionally focuses on gender-identity, as the impact of gender-identity on experience in engineering is well-documented. Research questions focus on the expertise-experience-intuition overlap and were evaluated through qualitative data collection and analysis. Emergent results suggest a perceived disconnect between intuition and expertise development and intuition and decision-making approaches, amongst engineers of all career stages. Intuition is perceived to be integral to engineering work, but engineers are hesitant to rely on it. This thesis furthers existing knowledge of engineering intuition and provides a basis for future work in the area.

Introduction

Intuition is a cognitive construct cited as fundamental to the development of expertise and thought to be primarily developed through experience (Dreyfus, 2004; Horn & Mansunaga, 2006; Patel & Groen, 1991; Salas et al., 2010). While the complexity of intuition has led to widespread variations in its definition, literature generally points to “gut feel” or “instinct” as common themes amongst them (Dane & Pratt, 2007). Developing expert-based intuition allows professionals to use intuitive judgements to make quick and accurate decisions (Dane & Pratt, 2007; Miskioğlu, 2022). Substantial research has been conducted regarding how nurses and business managers use intuition in their roles. These professionals express the importance of intuition in practice (Aaron et al., 2020; Downey et al., 2006; McCutcheon & Pincombe, 2001, Penner, 1984; Pretz & Folse, 2011; Simon, 1987). Each of these disciplines involve high-stakes decision-making, and intuition emerges as a favored approach to making decisions more quickly and accurately (McCutcheon & Pincombe, 2001, Penner, 1984; Pretz & Folse, 2011; Simon, 1987). For example, a nurse may use their intuition to detect familiar patterns and ultimately anticipate changes in their patient’s condition (Pretz & Folse, 2011). As engineering is a career also centered upon high-risk decisions, intuition could be applied similarly to benefit engineering projects. However, intuition is not widely studied in engineering, prompting the need to expand existing knowledge.

Previous work conducted within the Miskioğlu group has identified that intuition is both relevant to and widely used in engineering practice among those with 6+ years of experience, yet not embraced within engineering curricula despite its importance in the field (Miskioğlu & Martin, 2019). The objective of my honors thesis work is to characterize the extent to which practicing engineers’ perception of engineering intuition varies by aspects of identity, particularly gender identity and career stage. With ample data collected and analyzed for engineering practitioners with six to 26+ years of experience in previous work, I focus on a population of engineers with five years of experience or fewer. Studying (1) perceptions of expertise, (2) approaches to decision-making, and (3) perceptions of intuition in parallel illuminates the relationships among these domains and further builds our understanding of engineering intuition in an effort to ultimately define the construct and apply relevant findings to educational practices.

The distinction between participants' level of experience in my study versus the previous work done by the Miskioğlu group will provide a basis for comparison to understand how career stage may critically shape an engineer's perception of their expertise, approaches to decision-making, and understanding of intuition. As early-career engineers have by default less experience, and thus less time to develop expertise and intuition, my work was motivated by the belief that there will be differences between the two populations. In addition to this focus on early-career engineers, I focus on gender identity in my analysis to provide an additional understanding of how gender dynamics in engineering play a role in shaping experiences related to perceptions of expertise, decision-making, and intuition.

Purpose and Research Questions

The Miskioğlu group aims to uncover how engineers perceive and use intuition, and to inform evidence-based educational practices that bridge the gap between theory and practice to facilitate intuitive decision-making and expertise development. Existent literature on the development of expertise and decision-making extends to engineering students and practitioners, but there is not a clear focus on early-career engineers (Aaron et al., 2020; Miskioğlu & Martin, 2016, 2017, 2018, 2019). Gaining insight on the perceptions of expertise, decision-making, and intuition of individuals transitioning between academia and their established career will advance our knowledge on the development of intuition. Additionally, insights gained from this study will be used to further strengthen previous work completed by the Miskioğlu research team or provide new perspectives to address the existing gaps in our knowledge of engineering intuition. In this honors thesis, I address the following research questions:

1. How do early-career engineers frame their perceptions of their personal expertise?
2. What decision-making methods do early-career engineers use?
3. What do early-career engineers understand engineering intuition to be? And do they believe that they use engineering intuition themselves?

In addition, I also examine the potential impacts of career stage and gender identity in the context of each of these questions.

Relevant Background

This work is situated within frameworks of expertise development and decision-making, and the role of intuition in relation to each of these domains. The relationship between intuition, expertise, experience, and identity that forms the basis of my theoretical grounding is informed by existent frameworks of expertise and decision-making and mechanisms of identity. I leverage the previous and on-going work of the Miskioğlu group to inform my study design, strengthening the theoretical grounding and quality of the work. I introduce these areas of relevant background in the following sections.

Frameworks of Expertise & the Role of Intuition

An expert is defined as an individual with proficiency in a particular domain (Patel & Groen, 1991; Phillips et al., 2004; Seifert et al., 1997). Experts have extensive experience in their domain to draw upon when navigating their roles (Patel & Groen, 1991; Phillips et al., 2004;

Seifert et al., 1997). Here, I examine two key expertise frameworks: (1) Dreyfus Model of Skill Acquisition and (2) developments by Patel and Groen.

Dreyfus Model of Skill Acquisition

An individual works towards becoming an expert by advancing through various phases of skill acquisition, each marked by achieving key steps in comprehension (Dreyfus, 2004). The Dreyfus Model of Skill Acquisition identifies five phases: 1) novice, 2) advanced beginner, 3) competence, 4) proficiency, and 5) expertise. Gaining experience is the primary driver in the progression through these stages, in which repetition allows for the individual to recognize patterns within varying contexts and supports a gradual increase in subject-matter confidence (Dreyfus, 2004). Experience further facilitates one's working memory to categorize information more rapidly, which allows for the expert to filter out irrelevant information instantly (Dreyfus, 2004; Horn & Mansunaga, 2006; Salas et al., 2010). This ability is what sets an expert apart from the other phases of skill acquisition (Dreyfus, 2004).

Patel and Groen Model

Patel and Groen model domain-specific expertise development as a series of three phases: 1) novice, 2) intermediate, and 3) expert (Patel & Groen, 1991). An expert uses forward reasoning to solve problems, where they work "forward" from their specialized knowledge to progress into the unknown domains (Patel & Groen, 1991). Like the Dreyfus model of expertise development, this model distinguishes an expert by their ability to filter out irrelevant information (Dreyfus, 2004; Patel & Groen, 1991). Additionally, expertise facilitates efficiency in decision-making, similar to the Dreyfus model (Dreyfus, 2004; Patel & Groen, 1991).

The Role of Intuition

The use of intuition as a situational response to recognizable scenarios and the subsequent assessment of relevance is a distinct attribute of an expert (Dreyfus, 2004; Patel & Groen, 1991). Intuition is what drives the expert to immediately recognize what needs to be achieved and subsequently how to achieve that goal (Dreyfus, 2004; Gobet & Chassy, 2009; Patel & Groen, 1991). This manifests as the rapid filtering of subtle inputs to make quick and accurate decisions (Dreyfus, 2004; Gobet & Chassy, 2009; Patel & Groen, 1991). Intuition appears within expertise through these attributes, further strengthening the notion that intuition is a prerequisite to becoming an expert (Dreyfus, 2004; Patel & Groen, 1991). Existent intuition literature does not produce a clear definition of the construct of intuition, limiting the practical usefulness of the known intuition-expertise relationship. Intuition is described in numerous ways, such as being “direct and immediate knowledge”, “gut-feeling”, “instinct”, and “based upon experiences and emotions prior to rational analysis” (Dane & Pratt, 2007).

Dual-Cognitive Frameworks in Decision-Making

While definitions vary, intuition is widely considered a construct that exists outside of conscious reasoning, prompting its prevalence in theories regarding dual process cognition (Gobet & Chassy, 2009). Dual process cognition juxtaposes conscious thinking with the unconscious thinking in which intuition is rooted. Three cognitive frameworks that inform my work are: 1) fuzzy-trace theory, 2) domain-specific vs domain-general, and 3) System 1 vs. System 2 thinking (Gobet & Chassy, 2009; Khahneman, 2011; Penner & Klahr, 1996; Wolfe et al., 2005).

Fuzzy-Trace Theory

Fuzzy-trace theory contrasts “verbatim” and “gist” representations of experience, in which “verbatim memory” is used as a surface level approach to answering a question from memory, while “gist memory” is used when the question entails reasoning (Wolfe et al., 2005). Gist memory is cued when an individual is familiar with a scenario, which aids the individual in recognizing patterns and assessing relevance. Advanced cognition is said to be represented by pulling from gist memory (Wolfe et al., 2005). Gist memory can be seen as adjacent to intuition, as it aligns with expertise framework’s positioning of intuition as the instant recognition of patterns (Dreyfus, 2004; Miskioğlu & Martin, 2019; Patel & Groen, 1991; Wolfe et al., 2005). Numerous studies have used fuzzy-trace theory in this context to assess intuition in light of risk-taking, decision-making, and the development of skills. (Reyna et al., 2015; Reyna et al., 2015; Reyna & Ellis, 1994)

Domain-Specific vs Domain-General

Domain-specific knowledge refers to facts or information that is pertinent only to a specific domain (Penner & Klahr, 1996). In contrast, domain-general knowledge refers to skills that are applicable (translatable) across numerous domains (Penner & Klahr, 1996). Domain-specific and domain-general knowledge interact with each other, which prompts problem solving (Siegler,1989). The relationship between expertise and intuition suggests that the construct is domain-specific (Dreyfus, 2004; Miskioğlu & Martin, 2019; Patel & Groen, 1991; Penner & Klahr, 1996).

Dual-System Theory

Kahneman’s popularized cognitive framework poses two types of thinking: System 1 and System 2 (Kahneman, 2011; Tay et al., 2016). System 1 thinking is described as a “reflex,” categorizing it as an intuitive response prompted by recognized patterns (Kahneman, 2011; Tay et al., 2016). System 1 thinking is often viewed as “automatic” (Kahneman, 2011; Tay et al., 2016). Conversely, System 2 thinking is more deliberate, cued by uncertainty or complexity, which prompts the use of logic and reason (Kahneman, 2011; Tay et al., 2016). System 2 thinking is analytical in nature and is thus a much slower paced process (Kahneman, 2011; Tay et al., 2016). This study situates System 1 thinking as essential to understanding the ties between expertise, intuition, and decision-making, as it is analogous to intuition (Kahneman, 2011; Aaron et al., 2020; Tay et al., 2016). Experts rely on System 1 thinking, but it often is not without error, rendering the interaction between System 1 and System 2 thinking critical to successful expert performance (Kahneman, 2011; Tay et al., 2016). Numerous studies have used this framework to analyze the intersections between System 1 and System 2 thinking in academia and across different professions (Kannengiesser & Gero, 2019; Rottenstreich et al., 2007; Tay et al., 2016).

The nature of intuition documented in the frameworks discussed above further strengthens the notion that intuition is an integral aspect of expertise development displayed through decision-making mechanisms. The unconscious, rapid form that intuition takes allows for experts to know what needs to be achieved and how to achieve it immediately upon facing a recognized problem (Dreyfus, 2004; Gobet & Chassy, 2009). Because expert use of intuition occurs before rational analysis, experts are able to come to quick but accurate decisions, but only if a robust basis of experience exists for the expert to pull from subconsciously (Dane & Pratt, 2007; Dreyfus, 2004). Research in the fields of nursing and management further supports that the use of intuition enables fast and accurate decision-making (Burke & Miller, 1999; Hall et al., 2005). With the use of gist memory, System 1 thinking, and an overlap of domain-general and domain-specific knowledge, the expert is equipped to make intuitive decisions (Khaneman, 2011; Penner & Klahr, 1996; Wolfe et al., 2005).

Intuition in Engineering Education

While there is strong grounding for the value of intuition, there is hesitancy to use intuition in the professional world (Malzler et al., 2014). Many factors influence this disposition. Workplace culture perpetuates the notion that intuition is unreliable, and decisions should solely be made based on concrete evidence (Malzler et al., 2014; Lieberman, 2000). There are also power dynamics to consider, particularly for underrepresented populations. Professionals with more influence are in a position of privilege, where their use of intuition is less likely to (negatively) influence their career status and peer perceptions (Malzler et al., 2014; Weick, 1995). Conversely, populations with less power refrain from relying on intuition, as they do not have the same privileges (Malzler et al., 2014; Weick, 1995).

With theoretical grounding to show the necessity of intuition in developing expert engineers capable of making quick and accurate high-stakes decisions, I argue that the development of engineering intuition should be considered in engineering education. For example, previous work done by the research team determined that the lack of adequate time for problem-solving prompts the use of engineering intuition in practice (Miskioğlu, 2022). However, engineering is an evidence-based, technical career that conflicts with the nature of intuitive-based, unconscious approaches to decision-making (Dringenberg & Abell, 2018). This ideology is reflected in current engineering curricula, which focuses on rational, systematic, and human-centered processes of thought (Dringenberg & Abell, 2018). Intuition as a core decision-making mechanism is not widely accepted as a legitimate approach to solving problems (Dringenberg & Abell, 2018). Practicing engineers have reflected upon the importance of intuition in their career, yet a disconnect is still present between engineering education and real-world applications (Miskioğlu, 2022). Taken together, the role of identity in experience, the role of privilege in inhibiting or facilitating intuition use, and the perceived conflict between intuition as a "soft" construct and engineering as a "hard" discipline suggest that attention to identity is critical to understanding engineering intuition in context.

The Role of Identity

Identity is vast and complex; different identities are associated with different realms of life (Meijers, 1998). Acquiring new experiences requires subsequent placement of those experiences within the perception of oneself (Meijers, 1998). Belongingness within those experiences is an on-going, internal evaluation (Meijers, 1998). An identity one associates with their career may not align with other aspects of their identity, depending on the social and cultural constructs they associate each facet with (Blustein et al. 1989).

My work builds on previous research which highlighted the need to study perceptions of intuition among early-career engineers (Miskioğlu, 2022). Because experience is a crucial component in the development of expertise, and by extension intuition, lack of experience is a key attribute of this sample that will shed further light on the experience-expertise-intuition relationship. Furthermore, as the sample graduated from the same university, the type of institution acts as a common ground with regard to the nature of these formative experiences. My participant population intentionally oversamples women to ensure that gender disparities in perception are captured. I situate career experience and gender identity as the primary facets of identity of interest, able to influence perceptions of personal expertise, decision-making approaches, and use of intuition.

Career Experience

Academic experiences comprise the bulk of total engineering experience for early-career engineers. These experiences stem largely from engineering design experiences and institution type. Previous work has shown that academic design experiences can either enhance or worsen identification with engineering (termed engineering identity), as well as feelings of belongingness (Dannels, 2000; Godwin & Potvin, 2017; Rohde et al., 2019). Furthermore, these experiences have been shown to be linked to retention in engineering, in which students who leave engineering often pose a lack of identity with engineering as the cause (Rohde et al., 2019). It is feasible to infer that undergraduate academic design experiences play a role in forming engineering identity that extends outside of academia, as literature further cites recognition by peers, confidence in competency, and interest as additional influences on engineering identity (Dannels, 2000; Godwin & Potvin, 2017; Rohde et al., 2019). Gaining feelings of belongingness is initially fostered in academic design experiences, making them essential to shaping engineers early on (Godwin & Potvin, 2017).

It is important to acknowledge the type of institution this sample graduated from, as it may have played a formative role in fostering specific engineering design experiences. This sample was recruited from Bucknell, a small liberal arts college. These institutions are known for their small class sizes, which facilitate active learning by encouraging faculty availability and fostering supportive environments (Cech, 1999). In contrast to research-focused institutions' provide a less personal experience (Cech, 1999). Because experiences foster growth of identity, and also growth of expertise and intuition, viewing the sample in light of their academic experiences is critical to understanding emergent data.

Gender Identity

Women continue to be underrepresented in engineering (Wang & Degol, 2017) making gender identity of particular importance when considering a construct heavily reliant on experience. The lack of representation of women in STEM perpetuates systemic bias and sexism that is detrimental to women's retention in engineering, as developing feelings of belonging in the field are inhibited (Ahlqvist et al., 2013; Wang & Degol, 2017). The further overemphasis of negative feminine stereotypes contributes to the disconnect between gender identity and the nature of engineering shared by many women pursuing engineering roles (Cadaret et al., 2017; Ahlqvist et al., 2013). When multiple aspects of identity conflict in this manner, it leaves women at a disadvantage, as actively recognizing oneself as an engineer is critical to establishing identity, which continues to be interrupted for women by society at large (Ahlqvist et al., 2013; Cadaret et al., 2017; Rohde et al., 2019; Wang & Degol, 2017).

Male-dominated team environments often rely on gender as a "visible" identifier of knowledge and expertise, which promotes men's expertise to be valued over women's expertise, regardless of level of expertise or academic standing (Joshi, 2014). A long-standing history of the exclusion of women from STEM fields has perpetuated these surface-level assumptions, barring women from receiving proper recognition from their peers (Joshi, 2014, Wang & Degol, 2017). Furthermore, those viewed as having more expertise consequently have greater influence over decision-making and more opportunities to be in positions of leadership (Joshi, 2014). Therefore, women do not consistently have access to the same opportunities, which may be adversely discouraging to feeling recognized in career ambitions in the workplace.

Intuition has been shown to facilitate the growth of confidence (Lufityanto et al., 2016). With increased self-confidence in ability, individuals are more likely to remain in engineering

(Hall et al., 2015). This is of particular importance to women, who are faced with additional inhibitors in engineering as discussed (Ahlqvist et al., 2013; Wang & Degol, 2017). Women, as well as other underrepresented groups in engineering, are more likely to leave the profession as a consequence (Ohand et al., 2011).

Investigator Positionality

I am an undergraduate engineering student from the same institution as the sample population. I have been conducting undergraduate research on engineering intuition and adjacent educational topics for the entirety of my undergraduate career. My work is motivated by the belief that engineering intuition does exist, and this research is valuable. I recognize the potential for bias my positionality presents and have taken measures in my study design to minimize any impact it may have. In particular, the supporting research team was composed of an engineer and non-engineer to provide outside perspectives and consistently check over my results. In accordance with qualitative coding best practices, providing a positionality statement actively acknowledges what aspects of the study are at risk of subjectivity (Cohen et al., 2011).

Methodology

Both data collection and data analysis methods used follow best qualitative research practices (Cohen et al., 2011; Saldaña, 2021; Walther et al., 2017). These best practices ensure that high quality data, analysis, and interpretations are produced with respect to limitations of the study.

The validity of qualitative coding is posed to be dependent upon the following factors: credibility, transferability, dependability, and confirmability (Cohen et al., 2011). These aspects work similarly to quantitative factors of validity, ensuring external and internal validity, reliability, and objectivity (Cohen et al., 2011). This study follows these best practices to ensure that data analysis and subsequent interpretations are comprehensive and thus provide valuable contributions to the field. How I situated qualitative best practices within my work is summarized in Table 1 below.

Table 1. Qualitative Coding Best Practices (Cohen et al., 2011)

Factor	Quantitative Analog	Definition	How it is addressed in my thesis work
Credibility	Internal validity	The truth value, applicability, consistency, neutrality, dependability, and/or credibility of interpretations and conclusions within the underlying setting or group.	Literature is used to support emergent findings to ensure results are credible. Data collection continued until saturation. Multiple team members of diverse perspectives engaged in analysis.
Transferability	External validity	The degree to which results can be generalized to the wider populations, cases, settings, times, or situations.	Results are backed by clear, detailed, and in-depth explanations to allow for the reader to generalize results to other settings. Context of sample population emphasized in interpretation of results.
Dependability	Reliability	Dependability, consistency, and replicability over time, over instruments, and over groups of respondents.	Methodology used has been previously tested in the mid-to-late career study and produced valuable results.
Confirmability	Objectivity	Freedom from bias, analysis, and results independent of positionality.	By providing an investigator positionality statement, I recognize my own biases based on my position as a researcher in effort to be as objective as possible. Data collection and analysis is supported by a secondary researcher of differing background. Thorough documentation of analysis is undertaken and reviewed.

Sample

The participant population includes 10 practicing engineers in the early stages (0-5 years of experience) of their career. While this sample size is small, and sub-sample sizes even smaller, a sub-sample size of five is sufficient if data collection demonstrates saturation, i.e., new ideas do not continue to emerge from collected data (Cohen et al., 2011).

This population of early-career engineers was chosen as a direct counterpoint to previous work in the Miskioğlu group focusing on intuition use among practicing engineers with 6+ years of experience allowing for comparisons between the two populations. Early-career engineers have less industry experience to develop intuition, and subsequent expertise reliant upon it. The sample was intentionally split equally between self-identified men and women in order to oversample women and amplify the perspective of this underrepresented group. All respondents self-reported their gender in an open-response and no additional gender identities were represented among the population.

Recruitment

Participants were recruited from a pool of Bucknell University engineering alumni. An email was sent to approximately 800 engineering alumni from all majors with graduation years between 2016 and 2021. Participants were selected based on an initial demographic screening survey to ensure diverse sampling and adequate sub-population group sizes within gender identity for meaningful analysis.

Data Collection

Interviews were conducted in Fall 2021, in accordance with best practices (Cohen et al., 2011; Saldaña, 2021; Walther et al., 2017). I used the interview protocol developed by the Miskioğlu group for the aforementioned previous work with experienced engineers, with minor adaptations to account for the difference in population (Aaron et al., 2020). Use of a previously tested interview protocol ensures quality of data collected (Cohen et al., 2011; Miskioğlu, 2022; Saldaña, 2021; Walther et al., 2012). The interview protocol is designed to capture participants' (1) academic and professional background, (2) perception and development of personal expertise,

(3) decision-making and problem-solving approaches used in the workplace, and (4) definition and perception of engineering intuition.

The interviews were completed via the online conferencing tool Zoom. Each interview was recorded to subsequently be transcribed. Two members of the research team were present at each interview, myself and a non-engineer. Participants were encouraged to only answer questions they were comfortable with. They had no obligation to answer all questions presented. I led the interview, while the secondary researcher observed and prompted me with any comments or questions via private chat messaging as needed. This approach ensured that the protocol remained consistent across the 10 interviews.

Interviews were semi-structured in nature, so while the interview protocol mapped out specific questions, wording of said questions and follow-ups may have varied slightly per interview (Aaron et al., 2020). The order of the questions asked was important to maintain, as the natural progression of conversation allowed for the intuition discussion to fall at the end of the interview. The benefit in delaying the topic of intuition was that we were able to get an understanding of whether the concept was brought up by the participant inherently. In doing so, we were able to get a sense of how day-to-day early-career decision-making is discussed without steering the conversation towards intuition.

Data Analysis

A robust qualitative coding process was completed in accordance with best practices (Cohen et al., 2011; Saldaña, 2021; Walther et al., 2017). This entailed preliminary work developing a codebook, thorough group discussions to ensure code consistency, and in-depth analysis via a qualitative analysis software tool.

Codebook Development

The nature of qualitative coding entails comprehensive analysis of text to find meaning (MacQueen et al., 1998). In the case of this study, the texts of interest are the transcriptions of the completed interviews. A codebook functions as a constructed boundary in which the analyst must remain in, in order to connect text systematically and consistently for various codes and constructs (MacQueen et al., 1998). Without clear code definitions and explicit code application, the coding process loses validity. Furthermore, the codebook should reflect the researcher themselves, as it functions to answer the desired research questions of their work (MacQueen et al., 1998).

Prior Work by the Miskioğlu Group

The codebook used in this study was a product of previous efforts by the team using the same interview protocol (Miskioğlu, 2022). Use of a previously developed codebook adds strength to analysis methods (Saldaña, 2021) and supports the feasibility of this work in a one-year project. The codebook was developed through an iterative process that began in Fall 2019 with a study of nurses, business managers, and engineers, through which the interview protocol was initially developed, and a preliminary codebook was produced (Aaron et al., 2020) capturing themes across disciplines. In the previous study centered on engineering practitioners with 6+ years of experience, the same interview protocol was used to gather further data, and the codebook was developed (Miskioğlu, 2022).

A code is defined by Saldaña as, "a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data" (Saldaña, 2021; Rogers, 2018). Codes emerge through analysis of text, subject to the judgement of the researcher themselves (Saldaña, 2021; Rogers, 2018).

Nine parent codes and nine subcodes ultimately comprise the original codebook (Miskioğlu, 2022) leveraged in this study. As data analysis proceeded, additional subcodes were created to aid in analysis, which are discussed in the remainder of this section.

Emergent Subcodes from Thesis Work

Subcodes were added either to aid in producing more thorough data analysis or were necessary to represent narratives that were absent from the previous sample. The sub-codes that were added for this study are:

1. Academic Experience: A subcode of Experience titled "Academic Experience" was added to the codebook, as it emerged as a prominent narrative upon analyzing Experience codes. Academic Experience was not needed as a subcode in the parallel study, as participants sparingly drew upon academic experience (Miskioğlu, 2022).
2. Expertise-Related Mindset Sub-codes: Expertise narratives prompted additional sub-coding, in alignment with the previous study (Miskioğlu, 2022). The additional sub-codes fall under the mindset parent code, characterized as either the type of skill reported as expertise (technical vs professional) or the degree of confidence associated with assertion of expertise (active vs passive). Table 2 is reproduced from Bolton et al.,(2021) and defines these additional subcodes as used in ongoing work from the group.
3. Categories of Intuition Definitions: In order to better categorize participant definitions of intuition, codes titled "learned" and "learned/innate" were added. If a participant's definition was marked as 'learned', they believed that engineering intuition is something that can be learned, primarily through experiences. If the participant's definition noted a belief that engineering intuition is something that can be taught but also entails some aspect of who a person is from birth, it was marked as 'learned/innate'. No participant regarded

engineering intuition as something that could not be taught, so 'innate' as a code did not emerge and was not included.

Table 2. Definition of Expertise-Related Mindset Subcodes (Bolton et al., 2021)

Mindset Sub-code	Definition	Examples from Interviews
Technical Skill	Qualities acquired by using and gaining expertise in performing physical or digital tasks.	"My expertise is high speed boundary layer transition…"
Professional Skill	Personality traits and behaviors; the behaviors you display in different situations.	"Being able to, to sit and look at things objectively."
Passive Ownership of Expertise	Lack of confidence in identifying with personal expertise.	"I wouldn't say I have like a deep expertise in something."
Active Ownership of Expertise	Presence of confidence in identifying with personal expertise.	"I know the products of my company better than probably somebody else who just quickly looked at the data sheet."

<u>Coding Process</u>

All ten interviews were coded separately by two team members, myself and the other interviewer, using the modified codebook. Group discussions followed, where transcripts were analyzed line by line. Discussion primarily focused on code consistency and emergent themes. Discrepancies across the two researchers' codes were addressed by re-evaluating the context of the statement and referring back to the codebook for clarification. If inconsistencies could not be resolved, a third team member was brought in to provide insight. Iterative group discussions continued until a singular version was compiled, consisting of the new, agreed upon coded transcript.

Capabilities of Coding Software, Dedoose

As group discussions took place, the agreed upon codes were digitally transferred into the qualitative coding software, Dedoose, in real time. This was done in effort to avoid error when digitally transferring the coded transcripts at a later date. Descriptors, where demographic information is stored in Dedoose, were assigned to each participant from their responses to the initial demographic screening. All nine parent codes and relevant sub-codes were also added into the program for subsequent use.

Dedoose has vast analytic capabilities. The tools most beneficial to the overarching goals of this thesis include code occurrences (hit/miss), code frequency, code application, and code co-occurrences as summarized in Table 3 below.

Table 3. Analytic Tools in Dedoose (Dedoose, 2022)

Tool	Definition
Hit/Miss	Displays number of cases in descriptor sub-groups with one or more excerpts tagged with a particular code.
Code Frequency	Depicts how often particular codes were used by each participant.
Code Application	Determines raw code counts.
Code Co-Occurrences	Determines how many excerpts exist where two codes overlap.

Breakdown of Analysis

Analysis was completed by breaking down the interview protocol by the construct of interest (expertise, decision-making, intuition). A high-level analysis of each interview as a whole was first conducted, followed by independent analysis of expertise, decision-making, and intuition. For expertise analysis, responses to the questions “Do you have an expertise? If so, what do you consider it to be?” were examined. For decision-making analysis, each transcript was cut down to only include the questions (1) “How do you go about making decisions on the job?” And (2) “Has your approach to decision-making change since you first started in your role?” Lastly, intuition analysis included only the following questions, (1) “How would you define the term: engineering intuition?”, (2) “Do you think you use engineering intuition?”, and (3) “How do you think engineering intuition is developed?” The question “Why didn’t you mention intuition previously?” was analyzed separately. Each subset of questions was analyzed separately.

Results & Discussion

Results are categorized first by emergent findings from the overall interviews, then a deeper analysis of each interview section. Tables summarizing code counts and code hits are located in the appendix. Data were analyzed by gender identity and career stage, aiming to provide answers to the research questions as stated previously.

General

Table 6 (Appendix) depicts the number of interviews a code emerged in (referred to as hits) and the number of code applications for each code. In descending order, the overall top codes based on number of applications were (1) Inhibitor/Facilitator, (2) Mindset, (3) Experience. Conversely, the least used codes in descending order were: (1) Anti-Experience, (2) Sensibility Check, and (3) Outcome. The following findings emerged from data analysis of the interviews as a whole: (1) the sample population draws heavily on academic experience and (2) women in the sample population report fewer workplace facilitators.

Early-career engineers are more inclined to draw upon academic experiences

Academic experience was frequently drawn upon by participants, with eight hits, unlike the population of mid- to late-career engineers where it was rarely mentioned (Miskioğlu, 2022). This suggests that engineers with five years of experience or fewer are more inclined to draw upon academic experiences, whereas engineers with 6+ years of experience draw upon their post-graduate experience (Miskioğlu, 2022). For example, Sara describes, “I have all of this, science and data and knowledge from school" in reference to intuition. This finding may simply reflect career-stage, as early-career engineers have had less time to learn through experiences in practice.

This finding situates academic experience as integral to the early-career engineer's perceptions of expertise, decision-making, and intuition. As previously discussed, team-based design projects in academic settings have been shown to influence student identification with engineering (Rohde et al., 2019), and liberal arts education offer experiences that increase confidence (Cech, 1999). As early-career engineers from a liberal arts institution, these experiences represent the bulk of the participants' professional experience in engineering.

Women highlight fewer facilitators than men

Men had approximately double the total number (41) of facilitator codes than women (20). Men typically reported facilitators such as learning from previous projects or academic experiences. For example, Martin claims, "I have the engineering background so I'm confident in my mental math and I have the experience in the field so I'm confident in the experiences I've gained which helps me to do things I do on a day to day…" where his confidence and prior experience act as facilitators in his day-to-day work. While women also reported past experiences as facilitators, there was more variety in response, including emphasis on the value of feedback, professional relationships, and confidence. For example, Sara explains, "I would say it really depends on the project manager and if you have an established relationship with a product manager."

In terms of inhibitor subcode counts, women had slightly more occurrences than men (41 and 34, respectively). Inhibitors expressed by women were frequently along the lines of lack of confidence and ambiguity. For example, Teresa explains, "So when I initially started, I was very hesitant in terms of being able to make decisions competently by myself." Men had similar instances of inhibitors.

Placing this result within the broad context of engineering and the documented challenges for underrepresented groups within STEM fields (Wang & Degol, 2017), it appears that men are able to draw upon more positive workplace experiences than women. Subsequently, this suggests that the discrimination women encounter in STEM careers, such as stereotyping, bias, and sexism limits their access/exposure to facilitators (Wang & Degol, 2017). The facilitator - inhibitors imbalance may perpetuate lack of belongingness in engineering and could perpetuate the low retention of women in engineering overtime (Wang & Degol, 2017).

Expertise

Table 7 (Appendix) depicts code count totals with respect to gender identity for the expertise portion of the interview. With the exception of the subcode 'Lack of Experience', men had greater instances of every code. Emergent findings regarding expertise allude to (1) an existent disconnect between expertise and intuition, (2) hesitancy to claim expertise in early-career, and (3) no emergent gender differences in how expertise is reported among early-career practitioners.

Expertise is not perceived to be linked to intuition

Interestingly, there were no occurrences of physiological codes in the expertise section of the interviews. The definition of the physiological code is adjacent to how intuition is often described in literature (Aaron et al., 2020; Shirley & Langan-Fox, 1996; Unpublished 2022) and it is a foundational element of engineering intuition identified in previous work (Miskioğlu, 2022). The lack of physiological codes suggests that this sample did not perceive their expertise to be intertwined with intuition. This result is interesting, as use of intuition is a necessary prerequisite to expertise (Dreyfus, 2004), but not unique to the early-career sample – the mid- to late-career sample also showed zero physiological codes within expertise perceptions (Miskioğlu, 2022). Thus, there appears to be a disconnect between perceptions of intuition by engineering practitioners and development of expertise as defined in the literature, regardless of engineering career stage.

Early-career engineers tend to be hesitant in claiming expertise

An interesting narrative emerged within the active and passive ownership of expertise codes among this population of early-career engineers; seldom did either code stand alone – most often, the codes appeared coded together (co-occurred in 6 of 10 interviews). These statements from participants were alike in that they were often framed by first emphasizing a lack of expertise or skill, followed by a firm declaration of what they believe their expertise to actually be. An example from Martin is as follows, "I have less of an expertise in some specific engineering and more of an expertise in engineering in conjunction with people management." Here, the expertise of "engineering in conjunction with people management" is introduced by denying expertise in "some specific engineering." The dismissal of expertise as a way to introduce genuine expertise was a trend distinctive to this sample – this trend was not apparent in the mid- to late-career population/sample study (Miskioğlu, 2022).

Hesitancy towards claiming an engineering expertise may stem from the complexity of the transition from a full-time student to full-time engineer, in which an exploration of identity occurs (Huff et al., 2019). With expertise being tied to identity, the establishment of an individual's expertise may add onto that complexity (Bolton et al., 2021; Huff et al., 2019).

Table 4. Sub-code Occurrences by Gender Identity (Hits)

	Women	Men	Total
Active Ownership of Expertise	5	5	10
Passive Ownership of Expertise	3	3	6
Technical Skill	5	4	9
Professional Skill	1	1	2

Gender differences do not emerge in descriptions of expertise

Gender differences were not outwardly apparent across the additional sub-codes listed in Table 4 above, which differs from the parallel study in which men were more inclined to claim multiple areas of expertise and report technical expertise even when no longer in technical roles (Bolton et al., 2021). The lack of professional experience and shared institutional context may have acted as unifying features across the sample, making gender disparities less apparent when discussing expertise. Small liberal arts universities are favored for their small class sizes and faculty availability, which fosters active learning and supportive environments (Cech, 1999). In addition, literature points to liberal arts education as a facilitator for female retention in engineering, as courses are shaped to encourage increased confidence (Ellis et al., 2005). The environment in which this sample was exposed to during their academic career potentially acted as a neutral common ground.

<u>Decision-making</u>

Experience, mindset, and inhibitor/facilitator were the most used codes (by count) in the decision-making section, in alignment with overall results. Of these top codes, women represented a greater percentage of total code counts for each (70%, 64%, and 70% respectively). However, the only codes to be used by every participant were logic and mindset. Results are summarized in Table 8 in the appendix.

Findings emergent from analysis of decision-making applications include 1) the importance of mentorship for underrepresented populations and 2) the perception of intuition as an illegitimate decision-making approach.

Mentorship is integral to experiences of underrepresented populations

Basing decisions on experiences, particularly second-hand experiences, emerged as a favored approach among women, with 76% of second-hand experience subcodes coming from women. The most prevalent form of second-hand experience that emerged was mentorship. For example, Teresa explains "…so I would find myself, you know, reaching out to other engineers, reaching out to other people to get their opinions." Conversely, men in the sample more prominently reported constraints (59%) and logic (60%) when making a decision. For example, Martin explains his decision-making approach as, "Making the most cost-effective decisions to affect the most amount of people, because you know it's funded by the taxpayers, they pay their taxes to have nice things and so trying to balance that out and get the most out of the money is what drives my decisions."

Literature points to both recognition from peers and strong mentors as key facilitators to underrepresented groups gaining a sense of belonging in STEM (Aish et al., 2017; Amelink, 2008; Atkins et al., 2020). Successful mentorships focus on individual growth, providing support, and are personal to some extent (Crisp & Cruz, 2007). The importance of mentors within underrepresented groups in engineering may explain why women gravitated towards mentors when faced with a decision. Because men, particularly white men in this sample, are not in positions within engineering where they are generally underrepresented, mentorship may be less essential a contributor to their engineering identity, and thus less important to them overall.

Men tending to use pure logic and focus on constraints to base decisions indicates a level of comfort in career identity that underrepresented groups do not have the luxury of having.

Early-career engineers do not view physiological as a legitimate approach to decision-making

Decision-making approaches that were less pronounced among participants included physiological and sensibility check, each with only 3 code applications. One physiological excerpt from Teresa even emphasizes that “the gut reaction is not always the best avenue to pursue or the most efficient.” The remaining mentions of physiological decision-making are within contexts that imply that it was the only option to pursue. For example, Tim explains “you’re going to have to go with a little bit of your gut” in reference to lacking adequate information for problem solving. Thus, it appears that this sample does not view using what they consider “gut feel,” often conflated with intuition, as a legitimate decision-making approach.

This disposition among early-career engineers suggests there is a difference in perception with regard to physiological approaches to decision-making compared to mid- to late- career engineers (Miskioğlu, 2022). While some participant responses within the mid-to-late career population indicated that “gut feel” was used out of necessity, seven participants brought up the use of physiological approaches to problem solving without any prior mention of intuition (Miskioğlu, 2022). For example, one man states, “I think I rely on some, some instinct if something doesn’t feel right.” When looking specifically at instances of physiological codes amongst the more experienced sample, it appears that experience played a major role. Specifically, of those with 26+ years of experience (n=6) half mentioned the use of physiological as a component of their decision-making processes (Miskioğlu, 2022). The emergent trends in the mid-to-late career population in comparison to the early-career population suggests that the acceptance of physiological as a decision-making approach increases with experience.

Expert leveraging of past experiences is the crux of intuition (Dreyfus, 2004; Miskioğlu, 2022). When faced with a decision, an expert uses past experiences and an overview approach to problem solving to trigger intuition in an unfamiliar scenario (Dreyfus, 2004; Sauter, 1999). Later career engineers have more experiences to draw upon when use of intuition is prompted. Perhaps in consequence, later career engineers are better able to understand intuition as integral to their expertise development, hence why there is greater acceptance of intuition as a legitimate approach to problem solving as one's career advances.

Intuition

The most used codes in the intuition section are in alignment with the overall results, including mindset, inhibitor/facilitator, and experience, as shown in Table 9 (Appendix). However, no codes appeared consistently in all 10 interviews. This is a stark contrast with the population of engineers with 6+ years of experience (Miskioğlu, 2022) where both experience and mindset-focused appeared in the intuition section across interviews. This contrast suggests that perceptions of intuition converge among practitioners over time.

Data analysis reveal potential conclusions, including (1) how engineers perceive intuition development, (2) first-hand and academic experiences are integral to intuition development, (3) gender identity effects perceptions of engineering intuition, and (4) there is a disconnect between perceptions of engineering intuition and its use in practice.

Perceptions of intuition development were that it is either a learned or a combination of learned and innate ability

Gender did appear to have a slight influence on the way in which a participant regarded the development of engineering intuition (Table 9). Men were slightly more likely to believe that intuition has an innate component. In general, however, the sample regarded engineering intuition as something that can be learned. For example, Molly expresses, “I guess engineering intuition isn't necessarily something that you just have, it’s something that you gain, and you learn”. This result is similar to the mid-to-late career study, in which all participants stated that engineering intuition could at least in part be learned through experiences (Miskioğlu, 2022). The comparison of these results across samples of varying experiences strengthens the notion that perhaps engineering intuition is a skill that is learned overtime and suggests that it can be incorporated into engineering education. By refining their engineering intuition during their engineering education, engineers may be better set up to further develop engineering expertise throughout their careers, as the two constructs develop hand-in-hand (Dreyfus, 2004).

Table 5. Sub-coding Regarding the Development of Engineering Intuition

Sub-code	Women	Men	Total
Learned	4	3	7
Innate	0	0	0
Learned/Innate	1	2	3

Participants who regarded engineering intuition as a skill that can be learned, but is innate to a certain extent, were found in both comparative samples as well (Miskioğlu, 2022). For example, Richard (early-career) states, “…I think part of it is just a natural, just a natural thing because, you know, there's some people that like reading and writing more than doing math and science, so I think it is a little bit of just how certain people's brains are wired, but I do think that it can be developed.” The fact that some engineers purposefully turn to innate ability to explain the complexity of engineering intuition, and perhaps also as justification for why they are able to use engineering intuition themselves, is an interesting finding that would suggest that some engineers believe that the extent to which engineering intuition be taught is limited.

Literature has traditionally rendered innate ability as irrelevant in the development of expertise, and by extension intuition (Ericsson et al., 1993). Rather, an emphasis on experience is more relevant (Ericsson et al., 1993). Recent studies challenging these frameworks suggest that perhaps innate ability is more influential than previously viewed, emphasizing that there is sufficient evidence demonstrating that individuality does play an important role in shaping performance (Kulasegaram et al., 2013).

Growth-mindset (supporting ability to be learned) versus fixed-mindset (supporting innate ability) is a highly debated topic in literature (Dweck, 1999; Hochanadel & Finamore, 2015). Results indicate that practicing engineers do believe that engineering intuition can be learned – what remains unknown is how it is developed and to what extent. Literature alludes to experience being essential to expertise development, and in turn intuition development (Dreyfus, 2004; Patel & Groen, 1991; Unpublished 2022). The emergent results support expertise and intuition literature.

First-hand experiences promote the development of engineering intuition

Experience was a top code used in the intuition section, with 10 hits and 33 occurrences. First-hand experience was the particular experience route that was discussed the most (67% of all experience codes within intuition), indicating that this sample believed that intuition is primarily developed based on experiencing scenarios directly. For example, Sara explains, "For me, I learned a lot like I said hands on in the field, I was like thrown into the deep end like hey figure it out. And so that's how I learned." This result is in alignment with expertise framework, in which intuition is developed over experiences as an individual works towards expertise (Dreyfus, 2004; Patel & Groen, 1991).

Academic experience is integral to early-career engineer's perception of engineering intuition

Approximately 90% of academic experience code applications appear in the intuition section. Academic experience codes represent 31% of experience codes in intuition and appeared to be prompted by participant intuition definitions, primarily used to back up their proposed definition or how they believed it to be developed. In particular, all ten responses included that intuition is built upon previous experience – six specifically including academic experience. For example, Teresa defines intuition as, "…using your background and your knowledge from projects and classwork and different situations to make a better decision and to make the most logical decision."

The mention of academic experience directly in engineering intuition definitions was a trend unique to this sample – again, academic experience was not relevant in the mid- to late-career sample (Miskioğlu, 2022). While engineering intuition definitions varied from person to person, the inclusion of academic experience appeared to be important enough to incorporate within the majority in the early-career sample's definitions and suggests that the type of experience that drives intuition is dependent on career-stage.

Gender identity influences perceptions and application of engineering intuition

Men and women diverged in their perception and application of intuition. Men had an overwhelming majority of future codes in the intuition section, accounting for 74.1% of future codes. Future codes appeared as system-level thinking or anticipation with regard to use of intuition. For example, Martin reflects, "So I would say engineering intuition is being able to look at something and know what path you need to take right away." To the contrary, women accounted for 60% of logic codes, which often appeared in the form of using learned knowledge to support intuitive choices. Molly explains, “I think I do use engineering intuition, however, you got to be careful when using that concept, because you have to have facts to back it up.”

Gender differences regarding inhibitors and facilitators to intuition use were also apparent. Women had more occurrences of inhibitors than men, accounting for 80% of all inhibitor codes in the intuition section. Inhibitors appeared commonly as lack of knowledge or social dynamics. For example, Molly explains, “…you're challenged and you're working with different types of people, you're working on different projects and different scopes and interpretation, implementation...” Conversely, men had much more occurrences of facilitator codes, with 75% of total facilitator codes. Facilitators emerged as tools beneficial to intuition development or adequate knowledge. For example, Tim explains, “I think I’ve gotten sort of lucky that people have seen me definitely in leader leadership positions…and maybe it's because they see something on that intuition front.”

A quote of particular relevance to this dynamic from Molly reads as follows, “It's funny because a lot of engineering intuition can seem as arrogance to other departments that we work with.” This specific quote prompts the question: for whom does the use of engineering intuition come off as arrogance?

The larger presence of logic and inhibitor codes among women potentially contributes to answering this question. In excerpts among women coded as logic, half of total excerpts mention needing facts to back up their intuitive thoughts. Within inhibitor codes, this same dynamic appears as a hesitancy to solely rely on intuition without some other kind of backup. This hesitancy towards engineering intuition also emerges in the physiological codes. Only three women had physiological code occurrences. Two of those women specifically mention that they definitively do not rely on engineering intuition. For example, Maddie explains, “I definitely do not rely on it.”

Conversely, all five men had occurrences of physiological codes, and men accounted for 10 physiological experts, with hits for all five men. Physiological codes from men did not display a hesitancy towards intuition use, but rather talked about how they actively used intuition in practice. For example, Patrick explains, “I think it just is, for me, it seems like that knack to just understand if things are going to work…”

As previously discussed, the underrepresentation of women in STEM careers perpetuates negative stereotyping and bias that hinders women from feeling accepted by their peers (Wang & Degol, 2017). Literature additionally suggests that women’s expertise is held at lesser value than their male co-workers (Joshi, 2014). Perhaps because intuition and expertise are so heavily intertwined with one another, the discouragement of women’s expertise may additionally have adverse effects of perceptions and use of intuition among women in engineering. Fear (or experience) that their intuitive solutions will be discounted due to their gender identity may prompt their reliance on logic. Additionally, they’ve likely have been forced to back up their intuition more frequently, as it is not taken at face value, further explaining the greater presence of logic codes. The greater presence of physiological codes in men’s excerpts further supports this potential explanation – men’s expertise, and subsequent intuition, are valued in the workplace at surface-level as the standard and thus perhaps they are more comfortable using intuition without fear of being ridiculed.

Closing Question: “Why didn’t you mention intuition prior?”

The last of the interview questions prompted participants to think about why they had not brought up intuition within their other responses regarding expertise and decision-making. The aim of this question was to understand perhaps why intuition is not something that comes to mind when asked about expertise or decision-making. Two participants pointed out how intuition is not a commonly discussed concept in engineering, expressing some degree of hesitancy. For example, Teresa explains, “I don't know, maybe people would be hesitant of the term.” Seven participants reflected that engineering intuition is something that they had not thought to consider but had acknowledged prior that intuition is a subconscious action they actively engage day to day. Richard suggests, “I never really stop and think like you know what made what made us do this… it kind of is just something in the back of your head that…as you're working, you're making decisions and you're using intuition, but I guess you never actively stop and say, ‘Oh, I'm using intuition currently.’”

The other common response revolved around how intuition is not perceived to be an acceptable reasoning device. For example, Martin claims, “If I can be completely candid… I pretty much strictly deal with the public and the public doesn't want to hear that things are designed off of intuition, you know, the public wants to hear that I sat down for eight hours and I ran through all the math…”

One participant emphasized that they use engineering intuition, but do not rely on it completely. For example, Patrick examines, “Intuition seems to me almost like… it's a perk but not necessarily, you know, like make it a make-or-break type of like feature for someone to have.”

There is a disconnect between perception of intuition and use of intuition, regardless of experience

Mid- to late-career engineers expressed the same sentiment about engineering intuition as discussed above. However, the mid-to-late career study had a greater emphasis on defining engineering intuition as something “soft” or “touchy feely” (Miskioğlu, 2022). One woman claims, “…most of us call it [intuition] something like expertise, experience, you know” (Miskioğlu, 2022). There appears to be an avoidance of the word intuition all together. Nevertheless, every participant in the mid-to-late career sample claimed that they used engineering intuition in some sort of way, despite the acknowledgement of conflict between intuition and engineering practice (Miskioğlu, 2022). For example, when asked if they used intuition, one man even said, “Everyday because you, that's the only way you get shit done” (Miskioğlu, 2022). Thus, it appears a gap exists between perceptions of intuition within engineering and the acknowledged use of intuition in engineering practice. The hesitancy towards the topic depicts how intuition and engineering are at odds with each other. Intuition, while an integral part of expertise, is abstract and difficult to pinpoint (Dreyfus, 2004; Patel & Groen, 1991). Engineering on the other hand, is technical in nature, stereotypically perceived as a career based on data and concrete facts (Miskioğlu & Martin, 2019). Given that both samples addressed this disconnect, while simultaneously emphasizing the importance of intuition as a tool they use themselves, suggests that even with extensive experience, intuition is not generally accepted as a justifiable approach to engineering decision-making despite its widespread use.

Implications, Limitations, & Future Work

This work aimed to address gaps within existing literature regarding early-career engineers’ perceptions of expertise, decision-making, and intuition, prompted by previous work conducted by the Miskioğlu group. Implications on engineering education practices in context of the original research questions are discussed in the remainder of the section.

1. How do early-career engineers frame their perceptions of their personal expertise?

Regardless of career stage, the concept of intuition was not apparent in perceptions of expertise amongst either population. However, using intuition is known to be an integral component of expertise (Dreyfus 2004; Patel & Groen, 1991) and we see that intuition is widely used in practice among mid- to late-career engineers (Miskioğlu, 2022). A greater emphasis on developing intuition through formal educational practices or engineering design projects may be an avenue to actively facilitate the development of expertise.

Earlier attention to development of intuition could subsequently result in less hesitancy amongst early-career engineers in recognizing their personal expertise. The tendency to first deny expertise before claiming expertise was unique to this sample. Developing intuition may also strengthen student confidence in their expertise development and would be beneficial throughout the transitions from engineering student to early-career engineer to experienced engineer. Students that begin their engineering careers with greater confidence in their expertise may find that they are able to better identify with the career as a whole, thus increasing feelings of belongingness and encouraging retention (Blustein, 1989). This is particularly pertinent to women, as they are faced with inequality in the field due to the perpetuation of negative stereotypes (Wang, 2017). Fostering confidence in expertise by developing accurate intuition and the skills to acquire intuition in new areas may aid women in particular in developing identity within the career, thus working towards leveling the current state of inequality across gender in engineering.

2. What decision-making methods do early-career engineers use?

The few instances in which intuition, in the form of physiological, was brought up within decision-making by early-career engineers, it was only painted in a negative light. However, this perception appears to shift at some point after an engineer hits mid- career. The gradual acceptance of intuition within decision-making was seen with experience, which is expected based on existing frameworks of expertise and decision-making where expertise is characterized by use of intuition in problem solving (Dreyfus, 2004;Kahneman, 2011; Tay et al., 2016; Penner & Kalhar, 1996; , Wolfe,2005).

The reluctance towards intuition as a legitimate approach to making a sound, engineered decision has implications on the development of expertise within early-career engineers. Because experience appears to gradually help break the stigma regarding the use of intuition in engineering decision-making, normalizing the use of intuition in educational practices may help facilitate a more positive perception of intuition use and promote the acquisition of new expertise. Embedded in this is training students to understand the strengths and limitations of their intuition as it develops.

Again, there are particular implications for women that may extend to other underrepresented groups in STEM. My study indicates that women in this sample are more inclined to seek guidance from a mentor when faced with a decision, while men turn towards identifying constraints and using logic. This finding is well supported in literature regarding the importance of underrepresented engineers having access to proper mentorship in the workplace, as mentors become support systems (Aish et al.,2017; Hamilton et al., 2019). Fostering engineering belongingness through mentorship early on in engineering education is an advantage of the small liberal arts university environments, as small class sizes promote close faculty relationships (Cech, 1999). Prioritizing mentorship programs for underrepresented students would allow for university engineering culture to be inclusive, encouraging belonginess and retention.

3. What do early-career engineers understand engineering intuition to be? And do they believe that they use engineering intuition themselves?

Intuition was not mentioned before it was intentionally brought up in conversation, suggesting that the construct is detached from day-to-day engineering application and decision-making for engineers of all career stages. However, once intuition was introduced, every participant across both sample populations expressed their belief in the construct and provided their definition.

This finding supports that the use of engineering intuition is subconscious, and thus disconnected from expertise and decision-making perceptions. This disconnect from constructs that comprise a significant portion of day-to-day engineering work may explain the stigma against intuition use. Intuition itself conflicts with the nature of what is expected of engineering; engineering is expected to be technical and based on logic while intuition is abstract and even described by some participants as "soft."

If intuition is actively developed in the classroom and its appropriate use is consistently encouraged, it may lessen the stigma regarding the use of intuition in practice. This could appear in engineering education as the emphasis in team design projects to employ intuition to predict multiple outcomes of a particular scenario or to work on the refinement of the ability to recognize when design problems have insufficient information. Fine-tuning intuitive ability in engineering students has the potential to benefit engineering broadly.

Limitations & Future Work

The disconnect between stigma against intuition use and its actual widespread use by engineers seen across both my population of early-career engineers and the previous sample of mid- to late-career engineers supports the need for more work in the area of engineering intuition. This study was limited by institution type and lack of sample diversity. The Miskioğlu group hopes to continue to expand in this area of research to identify the boundaries of the construct of intuition and understand its application and development in greater detail.

Does institution type play a role in perceptions of expertise, decision-making, and intuition?

My sample was recruited from Bucknell Alumni from 2016-2021 and subsequently represents perceptions of this population. Conversely, the mid-to-late career sample was recruited from numerous institutions of varying types. Expanding the early-career sample to cover a wider range of institutions may provide further insight on how institution type subsequently affects perceptions of expertise, decision-making, and intuition. Coming from a small, liberal arts university, the current sample was exposed to abundant faculty availability and encouraging environments in their undergraduate education. It would be interesting to see how early-career engineers who graduated from a larger, research-based institution respond to the same interview protocol. Capturing students' experiences across institution type could further help identify how academic experience contributes to differing perceptions (e.g., mentorship, research, internship, etc).

In addition, the sample was comprised of only White/Caucasian individuals. Expanding the sample to encompass a greater diversity of race and ethnicities would assess whether results from my population transfer to other groups.

Is engineering intuition applicable outside of traditional engineering roles?

While all participants in the sample work as engineers, some are currently in a role where they are tasked with mostly non-engineering work or had recently changed roles (n=3). When this was the case, the participant was prompted to further elaborate on their perceptions of engineering intuition within their non-engineering role. More specifically, we were interested to know whether they believed that engineering intuition, in the way they perceived it, was applicable to their current non-engineering role. Each participant noted in their responses that they do use engineering intuition within their nontraditional engineering role. For example, Linda remarks, "…but I think in my mind engineering intuition is kind of using those problem-solving skills that we learned in undergrad to be able to influence some of our decision-making in the workplace, even if I'm not in a strictly engineering role…" While only a small sample size, participant responses indicated that engineering intuition may be applicable outside of traditional engineering roles suggesting that it is a translatable skill. Exploring this idea in future work could further strengthen the argument for enhancing engineering education to facilitate the development of intuition, as this finding would suggest that engineering intuition can be beneficial to success in other fields.

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<u>Appendix</u>

Table 6. Overall Code Hits & Counts by Gender Identity

Code		Women	Men	Total
Constraint	Hits	4	4	8
	Counts	18	33	51
Experience	Hits	5	5	10
	Counts	54	47	101
Academic Experience	Hits	3	5	8
	Counts	9	11	20
Lack of Experience	Hits	3	2	5
	Counts	4	2	6
First-Hand Experience	Hits	5	5	10
	Counts	30	30	60
Second-Hand Experience	Hits	5	3	8
	Counts	15	8	23
Future-Based	Hits	5	5	10
	Counts	24	52	76
Inhibitor/Facilitator	Hits	5	5	10
	Counts	59	75	134
Inhibitor	Hits	5	5	10
	Counts	37	32	69
Facilitator	Hits	5	5	10
	Counts	20	41	61
Logic	Hits	5	5	10
	Counts	28	41	69
Use of Logic	Hits	5	5	10
	Counts	23	30	53
Lack of Logic	Hits	3	5	8
	Counts	4	12	16
Mindset	Hits	5	5	10
	Counts	58	64	122
Outcome	Hits	3	3	6
	Counts	6	7	13
Physiological	Hits	5	5	10
	Counts	8	18	27
Sensibility Check	Hits	3	2	5
	Counts	8	3	11

*****Italicized text indicates sub-code

Table 7. Expertise Code Hits & Counts by Gender Identity

Code		Women	Men	Total
Constraint	Hits	0	2	2
	Counts	0	2	2
Experience	Hits	2	3	5
	Counts	2	3	5
Academic Experience	Hits	0	0	0
	Counts	0	0	0
Lack of Experience	Hits	1	0	1
	Counts	1	0	1
First-Hand Experience	Hits	1	2	3
	Counts	1	2	3
Second-Hand Experience	Hits	0	1	1
	Counts	0	1	1
Future-Based	Hits	0	4	4
	Counts	0	6	6
Inhibitor/Facilitator	Hits	3	5	8
	Counts	6	16	22
Inhibitor	Hits	2	5	7
	Counts	4	11	15
Facilitator	Hits	1	2	3
	Counts	2	5	7
Logic	Hits	0	2	2
	Counts	0	3	3
Use of Logic	Hits	0	2	2
	Counts	0	3	3
Lack of Logic	Hits	0	0	0
	Counts	0	0	0
Mindset	Hits	5	5	10
	Counts	6	10	16
Outcome	Hits	0	1	1
	Counts	0	1	1
Physiological	Hits	0	0	0
	Counts	0	0	0
Sensibility Check	Hits	0	0	0
	Counts	0	0	0

*****Italicized text indicates sub-code

Table 8. Decision-making Code Hits & Counts by Gender Identity

Code		Women	Men	Total
Constraint	Hits	3	4	7
	Counts	9	13	22
Experience	Hits	5	4	9
	Counts	21	9	30
Academic Experience	Hits	0	1	1
	Counts	0	1	1
Lack of Experience	Hits	2	1	3
	Counts	2	1	3
First-Hand Experience	Hits	2	4	6
	Counts	6	5	11
Second-Hand Experience	Hits	6	2	8
	Counts	13	4	17
Future-Based	Hits	5	4	9
	Counts	9	10	19
Inhibitor/Facilitator	Hits	5	4	9
	Counts	19	8	27
Inhibitor	Hits	3	3	6
	Counts	12	4	16
Facilitator	Hits	3	2	5
	Counts	5	3	8
Logic	Hits	5	5	10
	Counts	8	12	20
Use of Logic	Hits	5	5	10
	Counts	8	7	15
Lack of Logic	Hits	0	2	2
	Counts	0	5	5
Mindset	Hits	5	5	10
	Counts	18	10	28
Outcome	Hits	2	3	5
	Counts	2	3	5
Physiological	Hits	1	1	2
	Counts	1	2	3
Sensibility Check	Hits	1	2	3
	Counts	1	2	3

*****Italicized text indicates sub-code

Table 9. Intuition Code Hits & Counts by Gender Identity

Code		Women	Men	Total
Constraint	Hits	2	4	6
	Counts	4	12	15
Experience	Hits	5	5	10
	Counts	23	16	39
Academic Experience	Hits	2	3	5
	Counts	8	4	10
Lack of Experience	Hits	0	1	1
	Counts	0	1	1
First-Hand Experience	Hits	3	5	8
	Counts	15	11	22
Second-Hand Experience	Hits	2	1	3
	Counts	2	1	3
Future-Based	Hits	3	5	8
	Counts	14	20	27
Inhibitor/Facilitator	Hits	4	5	9
	Counts	18	18	34
Inhibitor	Hits	3	2	5
	Counts	12	3	14
Facilitator	Hits	2	5	7
	Counts	5	15	19
Logic	Hits	4	4	8
	Counts	14	8	20
Use of Logic	Hits	4	4	8
	Counts	10	7	16
Lack of Logic	Hits	2	1	3
	Counts	3	1	3
Mindset	Hits	4	5	9
	Counts	21	21	35
Outcome	Hits	0	0	0
	Counts	2	0	2
Physiological	Hits	2	5	7
	Counts	6	10	13
Sensibility Check	Hits	2	1	3
	Counts	6	1	7

*****Italicized text indicates sub-code