Characterizing Perceptions of Engineering Intuition Based on Experience and Gender

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Abstract
This full paper explores perceptions of intuition among engineering practitioners. Intuition is a characteristic of an expert that plays a role in many professional fields, including engineering. Interviews were conducted with 27 engineering practitioners with up to 26+ years of experience to better understand perceptions and development of intuition in an engineering context. The interviews had three areas of focus: expertise, decision-making, and intuition. This paper considers the area of intuition by addressing the following research questions: 'How would you define engineering intuition?' and 'How does engineering intuition develop?' Previous work has suggested gendered patterns of how practitioners discuss their expertise and the importance of experience in the development of intuition. These findings informed our specific interest in how level of experience or gender may affect participant responses regarding intuition. Qualitative coding of participant interviews showed that level of experience had no influence on how individuals defined engineering intuition. Gender comparisons revealed men to more often define intuition on the basis of innate ability or gut feeling whereas women more often defined the concept on the basis of past experiences. All participants highlighted the importance of experience in the development of intuition and provided multiple examples of helpful experiences they had, or wished they had experienced, which further underscores the importance of experience. The universal emphasis on experience's role in intuition development coupled with emergent gender difference in perception of intuition may point to the fact that experiences are not equally available to, or experienced in the same way, for all engineers. This suggests that providing equitable and diverse experiences in engineering education may be critical to foster intuition development.

Introduction
The idea of using intuition in professional practice has been established in nursing, business management, and the judicial system [1]-[5]. Recent work has extended the acknowledgement of discipline-specific intuition to engineering [6]. Intuition use in the workforce supports quicker and more efficient outcomes [1]-[7]. In engineering, intuition allows practitioners to navigate constraints and ambiguity in problem solving [6].

In models of expertise development, intuition is a skill specifically held by the expert and is used for making informed and accurate decisions without the need for time consuming analysis and consideration of alternatives [8]-[13]. Experience has been acknowledged as necessary for the development of expertise [8]-[12], suggesting it may also be essential to developing intuition. Previous work has demonstrated that early-career practitioners (< 5 years of experience) report using intuition despite being hesitant to claim areas of expertise [14]. This finding generates new questions around the relationship between level of experience and practitioner perceptions of intuition in the context of day-to-day problem-solving. We explore these new areas of inquiry by addressing the following research questions:

1. How do engineers of differing levels of experience define engineering intuition?

2. How do engineers of differing levels of experience perceive engineering intuition development?

Embedded in our exploration of these research questions is an interest in the role of gender. Women are underrepresented in STEM, especially in engineering [15], [16]. Women's expertise is often undervalued and less commonly recognized, regardless of their level of experience or educational background [17], [18]. This devaluation of women's perspectives in the workspace may in turn affect their perceptions and outward usage of intuition in problem-solving since intuition can be perceived as an uninformed approach. Our previous work has highlighted gender differences in practitioners' self-perceptions of their expertise, with women generally being more hesitant to claim expertise [14], [19]. We aim to build on that work by exploring gendered perceptions of intuition through the following complementary research questions:

3. How do engineers of differing genders define engineering intuition?
4. How do engineers of differing genders perceive engineering intuition development?

Our goal is understanding how engineering education can be improved to better prepare engineering students for their future careers. Intuition is a valuable skill in professional practice, including engineering [1]-[6]. Implementing interventions in undergraduate education to begin intuition development earlier has the potential to benefit those entering the future engineering workforce. We explore this space through one last research question:

5. What avenues for fostering engineering intuition in engineering education are suggested by participants' perceptions of intuition development?

Positionality

The investigation of engineering intuition is motivated by the research team's belief that engineering intuition is a necessary skill for engineering practitioners and thus deserves attention in engineering education. Here we acknowledge our interests and identities as an opportunity for reflection and transparency [20].

The first author is a non-engineer, woman undergraduate student. She is enrolled at a Primarily Undergraduate Institution (PUI) where the early-career engineer sample were alumni. Her positionality as a woman in STEM motivates her interest in gender differences in STEM. She is further motivated by the belief that experiences are critical in shaping who people are. Subsequent authors are faculty with higher education degrees in technical engineering disciplines or engineering education. These authors all have some level of industry experience and are motivated by their positions as scholars and educators working to prepare the future engineering workforce by bridging existent gaps between engineering practice and education.

To mitigate the potential biases that accompany these beliefs, we follow the quality management framework when applicable with thorough training, cross-checking, and interpretive awareness [21]. This framework addresses ways to collect and handle data to ensure validity, reliability, and accurate representation of data.

Limitations
The primary limitations of this study arise from the composition of the overall sample. The early-career sample is exclusively composed of graduates from a small liberal-arts PUI who identified as White. This shared context may explain similarities in their responses. The mid- to late-career sample includes participants with greater variability of educational backgrounds and demographic diversity, but still does not proportionally represent all non-dominant racial/ethnic groups. The lack of diversity in our sample is in part a symptom of the lack of diversity in the field [22]. Diversity in gender was partially addressed with the overrepresentation of women, but non-binary individuals are not represented. (Note: Zero individuals identifying as any gender other than woman or man responded to the solicitation). We also recognize that the sample sizes are relatively small. All data was collected until saturation [23]. Saturation was indicated by a lack of strikingly new ideas in responses during the interviews. Full detail on each sample and the data collection are described in Miskioğlu et al. [6] and Bolton [14].

Responses were active constructions captured at a single moment in time. Participants were not primed to discuss intuition prior to the interview, nor was this part of a longitudinal study. The early-career engineering practitioners and the mid- to late-career engineering practitioners are not the same people and thus have experienced different educational, occupational, and cultural environments. Subsequently, we cannot fully decouple whether differences in perceptions of these two groups are from years of experience or differences in experiences as the field evolves.

Methods
Twenty-seven engineering practitioners were interviewed with a previously tested protocol involving topics surrounding expertise, decision making, and intuition [1]. Their responses to the questions 'How would you define engineering intuition?' and 'How does engineering intuition develop?' from the intuition section of the interview were coded following Saldaña's [24] best coding practices.

Sample and Data Collection
The participants are engineering practitioners from 1.5 to 26+ years of experience, including retirees (Table 1). Further details regarding recruitment and demographics are in Bolton [14] for the early-career sample and Miskioğlu et al. [6] for the mid-to-late career sample. All participants self-identified as women or men in an open-response text box.

Data Collection is also described in detail in prior work [6], [14]. All interviews followed the same previously tested protocol [1], [6], [14]. This protocol includes three main interview sections: expertise, decision making, and intuition. In this paper, we are only interested in the intuition section of the interviews.

Table 1 Pseudonyms categorized by years of experience with gender identity, racial/ethnic identity, and degree discipline(s); tables adapted from Miskioglu et al. [6] and Bolton [14]

Level of Experience	Pseudonym	Reported Gender	Reported Race/Ethnicity	Years of Experience	Degree Discipline(s)
Early-Career (*n* = 10)	Ava	Woman	White/Caucasian	4	There is a mixture of Civil, Chemical, Biomedical, Structural, and Materials engineering practitioners but could make the participants identifiable if specified here.
	Linda	Woman	White/Caucasian	1.5	
	Maddie	Woman	White/Caucasian	3	
	Molly	Woman	White/Caucasian	4	
	Teresa	Woman	White/Caucasian	2.5	
	Bobby	Man	White/Caucasian	5	
	Martin	Man	White/Caucasian	2	
	Patrick	Man	White/Caucasian	2	
	Richard	Man	White/Caucasian	2.5	
	Tim	Man	White/Caucasian	4	
Mid- to Late-Career (*n* = 17)	Olivia	Woman	Asian	6-10	Civil
	Emma	Woman	Asian	6-10	Electrical and Aerospace
	Sophia	Woman	Asian & Native Hawaiian or Pacific Islander	6-10	Aerospace/Aeronautics/Aerodynamics
	Ella	Woman	Hispanic and White/Caucasian	6-10	Chemical
	Chloe	Woman	Black or African American	6-10	Aerospace
	Andrew	Man	White/Caucasian	6-10	Materials Science and Engineering
	Logan	Man	White//Caucasian	6-10	Materials Science and Engineering Management
	David	Man	Black or African American	11-15	Electrical
	Lily	Woman	White/Caucasian	16-20	Mechanical and International Business/Finance
	Grace	Woman	White/Caucasian	21-25	Computer Science
	Kevin	Man	White/Caucasian	21-25	Civil
	Mia	Woman	White/Caucasian	26+	Aerospace
	Haley	Woman	White/Caucasian	26+	Electrical and Systems
	Tyler	Man	Asian	26+	Electrical
	Dylan	Man	White/Caucasian	26+	Nuclear and Electrical
	Aiden	Man	White/Caucasian	26+	Mechanical and Construction Management
	Jacob	Man	White/Caucasian	26+	Mechanical

Data Analysis

Responses to the semi-structured questions ‘How would you define engineering intuition?’ and ‘How does engineering intuition develop?’ were extracted from the intuition section of all interviews and analyzed for this study. (Note: All participants reported that they believed engineering intuition exists and provided a definition.) These responses were then analyzed for common themes first with an open coding approach in which notable phrases were marked with labels that represented the participant's point of view [24]-[26]. These labels were applied to responses with the gender of the participant unknown. This decision was made conscientiously for interpretive awareness to anticipate potential bias in the first author's labeling decisions due to being a woman in STEM [21]. The majority of labels fit in two distinct categories, resulting in the emergent codes: Experience and Innate. Codes are defined in Table 2 and capitalized in use throughout the paper. Co-coding was used when both codes simultaneously fit the response [24].

Table 2 Emergent codebook

Code	Definition	Descriptors	Examples
Experience	Rooted in leveraging or gaining relevant experience.	experience, knowledge, the past, engineering-related work, background, tough classes, repetition	"Engineering intuition to me is[…]Well, what is more likely to work or not work based on experience" (Olivia) "[Engineering intuition development is] definitely through trial and error and experience." (Molly)
Innate	Based in having a natural ability or gut feeling.	innate, knack, gut feeling, general sense, engineer's touch, intangible, born with it, nature	"I think it just is, for me, it seems like that knack to just understand if things are going to work…" (Patrick) "I think some of it is, is just kind of part of our nature." (Dylan)

A second coder was brought in for cross-checking of data, to ensure accurate representation of the participants' point of view, and as a form of inter-rater reliability [21]. Inter-rater reliability was not calculated numerically due to a focus on consensus [21], [27]-[30].

Results & Discussion

Practitioners' definition of engineering intuition did not vary by level of experience but did vary by gender. Men more frequently defined the concept in terms that reflected Innate whereas women leaned on Experience in their definitions. Despite these differences in how engineering intuition was defined, there was largely consensus in participants' responses to how engineering intuition is developed. All participants attributed the development of intuition either completely or in part to Experience, underscoring the notion that intuition develops alongside expertise, as expertise is largely developed through experience [8]-[12].

Defining Engineering Intuition and Level of Experience

The basis of participants' definition of intuition does not appear to vary by level of experience, as the prevalence of Experience and Innate codes was similar in both groups (Table 3). The early-career engineers were evenly split, with half of the participants describing intuition as based on Experience and half as Innate. In the mid- to late-career sample, nearly half of the participants defined intuition as based on Experience (59%) or Innate (53%). (Note: Percentages sum to over 100% due to inclusion of co-code occurrences.) Two responses in each population included references to intuition as based both on Experience and Innate. This represents the perspective that engineering intuition is a more complex combination of Innate and Experience influences. For instance, Bobby, an early-career engineer, expressed that, "...it is a mix of having that sort of like visual anticipation and also a lot of experience…"

Table 3 Code-occurrences for definition of intuition by level of experience

	Experience Only	Innate Only	Co-Coded
Mid-to-Late (*n* = 17)	8	7	2
Early (*n* = 10)	4	4	2
Code Totals	12	11	4

These results suggest that a practitioner is equally likely to describe intuition as based on Experience or Innate, regardless of their years of experience. This finding is unexpected, as intuition is a characteristic of the expert, and expertise requires experience to develop [8]-[9]. Intuition and experience are likely also linked. We would expect that early-career practitioners may have different views of intuition stemming from their comparative lack of experience. Our data shows consistency in practitioners' perception of intuition that is independent of years of experience. This may suggest that perceptions of intuition are formed early and may remain constant over time. This finding may also be limited to this particular population of early-career engineers as they, unlike the mid- to late career engineers, come from a shared academic experience.

Defining Engineering Intuition and Gender

Participant definitions of intuition did vary by participant gender (Table 4). Men more often defined engineering intuition as Innate (69%) whereas women more often defined engineering intuition as calling upon Experience (79%). Three women and one man included both references to intuition as Experience and Innate.

Table 4 Code-occurrences for definition of intuition by gender

	Experience Only	Innate Only	Co-Coded
Men (*n* = 13)	4	8	1
Women (*n* = 14)	8	3	3
Code Totals	12	11	4

This observed difference between how men and women describe intuition may emerge from the tendency men have to attribute their qualities to natural ability whereas women attribute their qualities to the hard work they have done [31]-[33]. A common sentiment expressed by the women is exemplified by Molly from the early-career sample when she said, "I think I do use engineering intuition, however, it's you got to be careful when using that concept, because you have to have facts to back it up." Mia from the mid-to late-career sample had a similar experience in the workplace as shown by this excerpt highlighting when she uses intuition:

Mia: I won't always say it out loud, but I enjoy going and checking to see if I got it right. And it's usually pretty right [...] I didn't start trusting [my intuition] until I was in my 40s.

Investigator: Why do you think it took so long for you to trust that?

Mia: It might have something to do with being female.

Women feeling the need to justify their decisions in the workplace is not new and is a common gender disparity that stems from years of being undervalued and not taken seriously [17], [18].

Development of Engineering Intuition
All participants expressed that experience is necessary for engineering intuition development, including the 41% of participants (eight men, three women) who specifically did not acknowledge experience in their definitions (Tables 5 & 6). These results suggest that intuition is widely perceived as developed by experience, and further supports its alignment with expertise [10]-[12], [34]-[36]. This simultaneous development of expertise and engineering intuition is further supported by the strong emergence of Experience as a topic of discussion in both the expertise and intuition sections of the full interviews for both datasets reported in our prior work [6], [14].

Table 5 Code-occurrences for intuition development by level of experience

	Experience Only	Innate Only	Co-Coded
Mid-to-Late (*n* =17)	12	0	5
Early (*n* =10)	8	0	2
Code Totals	20	0	7

Table 6 Code-occurrences for intuition development by gender

	Experience Only	Innate Only	Co-Coded
Men (*n* =13)	10	0	3
Women (*n* =14)	10	0	4
Code Totals	20	0	7

The unanimous occurrence of Experience for engineering intuition development is a stark contrast from the nearly even occurrence of Experience and Innate in the participants' definitions.

Comparing Definitions and Perceptions of Intuition Development
Many participants (56%) expressed that engineering intuition is Innate in their definition (41% entirely, 15% in combination with Experience). This position is at odds with the potential for

intuition to be developed. This perception of engineering intuition as Innate suggests respondents may have a fixed mindset towards intuition as a skill. Fixed mindsets in education can lead to stagnancy and prevention of succeeding [37]-[40]. Adopting this kind of mindset has the potential to exclude those who do not seem to be born with this skill.

This Innate perspective did not emerge as strongly when participants were asked explicitly about how engineering intuition develops. The 26% of participants that described intuition development in Innate terms also used Experience terms and claimed that though engineers may be 'born with it,' experience helps develop intuition further. This is a perspective that is more consistent with a growth mindset. This result may reflect a tension between participants' perspectives about intuition as a construct versus how it is developed, or it may be an artifact of the progression of the interview. The definitions of intuition were solicited without warning, so what was captured is the initial thoughts of the participant. Most participants gave the question some thought before answering even though they were processing their perspectives in real-time. Follow-up questions may have led to shifts in their perspectives as they thought about intuition more. All participants were offered the opportunity to add a final comment before concluding the interview, but we did not explicitly ask if they still agreed with their initial definition. It is possible their definitions might have shifted with further thought to more consistently include Experience. Regardless, the consistent emergence of Experience in responses to how engineering intuition develops underscores the importance of gaining relevant experience for engineering practitioners and students. Participant responses included emphasis on specific types of experiences, giving us some insight into what they may deem relevant experience.

Suggestions from Participants

Participants independently offered a wide variety of suggestions for how to incorporate the development of engineering intuition in education. Ideas include the incorporation of hands-on experience, using ill-structured problems, keeping the individual learner in mind, and encouraging mistakes. They also highlighted the benefits of having teachers who are dedicated to their growth and success. Responses from the participants for each of these suggestion areas are quoted to give participating engineering practitioners a direct voice [6], [14].

1. The importance of direct, hands-on experience:

> *"I use more of the knowledge I learned being on site and doing things in person…than I ever learned from a class." (Martin, early-career)*

> *"It's not enough just to see a couple powerpoint slides on something. You actually have to live through it." (Andrew, mid-to-late career)*

> *"For me, it would be courses that were not lectures, courses that were more hands-on, a little more lab work, shop work than then just sitting in a lecture. Conversational courses where there is give-and-take between the educator and the students." (Lily, mid-to-late career)*

The integration of more hands-on experience is crucial for the continued development of engineering education. Hands-on experience in post-secondary education is both a catalyst for learning and a confidence booster [41]-[43]. It is even more-so for underrepresented groups [44]. The integration of more hands-on experience is thus crucial for the continued development of engineering education.

2. The value of ill-structured questions:

> *“the Professor wasn't giving you a clear problem and you didn't know exactly which formula to go ahead and solve with” (Linda, early-career)*
>
> *“an open ended, you know here's this problem that you have, and like we're going to give you like a solution for it, but it doesn't mean that it's, the only solution and like you're more than welcome to use the tools available to you to update and like streamline that process” (Patrick, early-career)*

Questions that allow students to think outside of the box aid in the development of engineering intuition. Ill-structured problems are open-ended and complex, and are quite common in engineering practice [45]-[48]. These types of questions inspire creativity instead of calling for solutions based on rote memorization. This is like hands-on experience for the mind and is crucial for the development of more advanced skills like engineering intuition.

3. Willingness to let students make mistakes:

> *“being willing to to make mistakes in a safe a way” (Tim, early-career)*
>
> *“a lot of trial-and-error.” (Jacob, mid-to-late career)*

The traditional educational grading system punishes mistakes rather than embracing such opportunities as learning experiences. One such way to restore this freedom in truly experiencing education without the fear of getting things wrong is through alternative grading options [49]. Competency based education is an approach that focuses on preparation for professions in which students are given the opportunity to re-do assignments and practice as much as they need until they receive a grade that demonstrates an understanding of the topic [50]-[52]. This creates an environment where making mistakes is okay and can be a catalyst for engineering intuition development.

4. Keeping the individual learner in mind:

> *“this is going to vary for everyone, because of the type of learner that people are” (Bobby, early-career)*
>
> *“I think it kind of depends on the individual" (Ava, early-career)*

Keeping the individual in mind and adapting pedagogical approaches is particularly necessary for creating an accessible environment that is welcoming to neurodiversity [53]-[54]. Presenting material in a variety of ways can help accommodate for the fact that not everyone is the same in the way they think and process material. Rather than tailoring to the way in which each individual seems to learn best as a learning styles approach may suggest, it is important to vary material for all students to facilitate learning with multiple approaches to thinking [55].

5. The influence of encouraging, dedicated educators:

> *"in college, it's great having the educators who try to nurture the person, the personal side of it, as well as just the pure academic side of it. And I think that's part of what helps draw it out of people. To be reassured that yes, you're doing it. Your inquisitiveness is good, it's healthy. And let's do more of that." (Lily, mid-to-late career)*

Intuition development can be aided by a setting in which students feel like they have a place and are making the right decisions. Encouragement from professors, mentors, and others in academia positively impacts educational development, especially for those in underrepresented groups [56]-[58]. It also strengthens the confidence and perseverance of students [56] which then helps with retention in the field. Greater retention means more opportunities for more experiences that would help develop engineering intuition. Additionally, having professors and mentors that promote a growth mindset in their support and encouragement creates environments that increase feelings of belonging for students as well as promotes their success [59]. Support from others in engineering education is particularly important for marginalized individuals and has the potential to help further diversify the field.

Each of these suggestions advocates for the integration of new experiences into engineering education as a means for promoting intuition and expertise development. In many cases, educators are making efforts to incorporate these suggestions already. It could be that students do not lack the experience itself but need support in making the most of their experiences. Many of these suggestions already exist in the educational model of the PUI from which the early-career engineers were alumni. This may explain why each early-career engineer claimed to have and use engineering intuition and were able to elaborate on how it is developed [14] despite having little experience as a practitioner.

Implications for Engineering Education

Intuition is a domain specific skill of the expert [6], [8]-[10]. Reliable intuition requires expertise, and relevant experience [6], [8]-[10], [12], [60]-[61]. What is perceived as faulty intuition is often a result of novice status rather than intuition itself, which can lead individuals down an incorrect path. All participants in our sample claimed to have a domain specific expertise [6], [14] and there were no cases where participants described intuition use leading them astray [6]. Undergraduate students have not typically developed the same domain specific expertise as our sample of practitioners. It is important to foster the development of expertise at the undergraduate stage so that development of intuition can occur in tandem. Development of intuition also requires adoption of a growth mindset with respect to this skill. Over half of our participants (56%) mentioned that engineering intuition is an Innate ability. A prevalent belief that intuition is innate in academia may hinder efforts to adopt intuition developing interventions.

The consistent emergence of Experience in both definitions for and the development of intuition in women's responses highlights the importance of providing equitable experiences for women. This underscores current work in creating more accessible experiences for women (e.g., co-curricular experiences), which have been associated with student well-being, academic success, self-regulation of goals, and employment self-efficacy perceptions [62]-[63]. This could reduce women feeling a need to compare themselves to men who have "innate ability." Gender was the only demographic identity focused on in this work, but these findings may extend to other underrepresented and marginalized groups.

Future Work

This work reflects perceptions at a single moment in time. Future uses of this protocol could explore longitudinal tracking of participants. Alternatively, the protocol should include an additional question at the end to prompt respondents to reconsider their initial definition of engineering intuition and change their definition if desired. This may uncover more of the ongoing complexity of engineering intuition and its relationship with experience.

Future work should also specifically seek to diversify the early-career sample to represent different demographics and educational experiences. The demographic comparison embedded in this study focused on gender. Obtaining a more diverse sample regarding race/ethnicity would allow for this work to capture a wider variety of perspectives that may vary from those presented in this study. The sample also included individuals with exposure to hands-on experience, ill-structured problems, some encouragement to make mistakes, diverse presentations of material, and support from mentors. Having these experiences that we advocate for may be why individuals with less than 5 years of experience as a practitioner claim expertise and use of engineering intuition [14]. The sample of early-career engineers should be expanded to include recent graduates of different institutions that are lacking in the suggestions addressed in this paper. In addition, continuing work is currently underway to further understand to what extent one's mindset affects the processing of experiences. This will further illuminate how much educators should be focusing on altering the experiences available or helping students see their experiences through a different perspective.

Acknowledgements

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