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Characterizations and Portrayals of Intuition in Decision-Making: A Systematic Review of Management Literature to Inform Engineering Education

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Abstract

Engineers' decisions drive the of design our ever-changing world. What engineers design, how they design, and who they include in the design process all involves decision-making. How those decisions are made ultimately impacts our quality of life. When making decisions, people (and therefore engineers!) utilize at least three distinct forms of reasoning: rational, intuitive, and emotive. Engineering education currently emphasizes rational approaches to decision-making. User-centered design experiences can expose students to the importance of developing empathy for the user throughout the design process, which can encourage emotive reasoning strategies. However, students' exposure to intuitive reasoning, which plays a role in all decision-making, is limited during their undergraduate engineering formation. In an effort to generate a baseline for how we can operationalize intuition in the context of engineering education, the purpose of our current research was to synthesize characterizations and portrayals of intuitive reasoning. We focused on literature from the field of management because intuition is considered in the context of complex, strategic decisions, which are reflective of the design decisions central to engineering. The specific research questions addressed in this study are 1) how does extant management literature characterize intuition?, and 2) how does extant management literature portray the value of intuition? To answer these research questions, the research team conducted a systematic literature review. The results of this effort provide a summary of the ways in which scholars have defined and portrayed the role of intuition with respect to complex decision-making. Based on this synthesis, we recommend that engineering educators develop innovative ways of teaching decision-making that does not remove the teaching of rational methods, but finds way to integrate intuitive reasoning. We provide brief recommendations for how we might begin to shift engineering education towards more realistic and inclusive ways of teaching decision-making.

Introduction & Background

Engineers' decisions drive the design of our ever-changing world. What engineers design, how they design, and who they include in the design process all involve decision-making. How those decisions are made ultimately impact our quality of life as a society. Over twenty years ago, Nair (Dane & Pratt, 2007) explicitly called for engineering education to utilize teaching approaches that consider the formation of engineering students as key decision makers in society rather than approaches with a strict focus on the development of their technical or analytical skills. It is well-established that real-world engineering problems are ill-structured and involve decisions with respect to many non-engineering constraints and standards for success (Jonassen, 2000; Jonassen, Strobel, & Lee, 2006). Inherent to the complex nature of engineering problems is the requirement to utilize multiple forms of reasoning, including intuition, to effectively solve them.

Common expectations of engineering graduates focus on the ability to solve open-ended, complex problems and incorporate intuitive reasoning in their problem-solving processes. For example, a recent revision of the undergraduate student outcomes by the Accreditation Board for Engineering and Technology (ABET) outlines an expectation for the modern engineer to solve engineering problems within dynamic contexts. This is present in the language of three of the seven ABET Student Outcomes proposed for the 2019-20 accreditation year, either implicitly as the application of design situated in complex social systems or explicitly as "judgement," as shown below:

> ***Student Outcome 2****: an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.*

> ***Student Outcome 4:*** *an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts*

> ***Student Outcome 6:*** *an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions (ABET, 2017)*

Furthermore, the ill-structured nature of engineering problems is characterized by the need for problem framing (Crismond & Adams, 2012; Jonassen, 1997) and the possibility of multiple solutions (Douglas, Koro-Ljungberg, McNeill, Malcolm, & Therriault, 2012; Dym, 1994).

Despite the clear need for engineers to make complex decisions, Picon (2004) argues that the single unifying theme across the range of engineering disciplines is the emphasis on utilizing rational reasoning in decision-making. Engineering's emphasis on rational approaches to decision-making is manifested in the public image of the field of engineering; non-engineers often subscribe to a "rational fallacy" that portrays engineering design and decisions to be a result of strictly logical and rational processes (Addis, 1990). Standing on the shoulders of math and science, engineering design decisions are, in fact, required to be evidence-based and defendable. As a result, engineering education primarily teaches the prioritization and selection practices for engineering decisions as rational and objective. For example, engineering design teams are commonly instructed to utilize rational decision-making tools, such as a decision matrix (Pugh method) or a quality function deployment procedure. A portrayal of rational tools as exempt from other forms of reasoning shows up in a recent publication recommending the introduction of decision matrices in K-12 to demonstrate the way that "they allow engineers to objectively examine solution options" (Gonczi et al., 2017, p. 8). Teaching practices and epistemologies within the culture of engineering communicate to students that valid decision-making is strictly rational.

The reality of human decision-making is far more nuanced than what can be taught in the form of rational methods. Recently, educators in operations research have proposed teaching complex decision making to undergraduates through a systems thinking approach (Yurtseven & Buchanan, 2016). In practice, designers may allow only a few factors to dominate their decision-making process (Dwarakanath & Wallace, 1995). Gainsburg and colleagues (2016) discovered that while practicing engineers justified their design decisions at the end of a project as though they flowed from a logical and rational process, their actual design process was much messier and full of informal reasoning. In their emergent framework for informal reasoning in making complex sociotechnical decisions, Zeidler & Sadler (2005) showed the presence of three different types of reasoning: 1) rational reasoning, which is primarily cognitive and utilizes reason and logic to formulate position on a decision, 2) intuitive reasoning, which relies instead on affect and shows up as immediate feelings or reactions, and 3) emotive reasoning, which includes a combination of cognition and affect and comes through as means of understanding the experience of a person (either real or imagined) such as empathy or sympathy. Each of these distinct reasoning patterns play a valuable role in decision-making, yet this holistic view of decision-making is often under emphasized in undergraduate engineering education.

In addition to a focus on rational reasoning, emotive reasoning has been integrated into undergraduate engineering education in the form of teaching user-centered design, which includes a focus on developing empathy for the user. Krippendorff (2005) claims that design has experienced a paradigm shift away from a focus on technology and towards a focus on humans. IDEO (2015) posits that all design should be human-centered as the design process must begin with consideration of the people who will benefit from the design; it is those people who are facing the problems that engineers wish to solve. This connection with the humans and their needs is central to all design (Zhang & Dong, 2009) and must play a role in engineering decision making. Therefore, engineers who conduct user research in the problem definition stage must utilize emotive reasoning. Engineering education has increasingly incorporated human-centered design process in their undergraduate formation (Buchanan, 2001) and shown that it has improved students' understanding of the importance of user research in the design process (Oehlberg & Agogino, 2011). Engineering education researchers have characterized the variation in how students experience user-centered design (Zoltowski, Oakes, & Cardella, 2012) and argued that effective engineers must be able to consider multiple perspectives in the diverse ways in which others define problems (Downey et al., 2006). While a distinction between rational and emotive reasoning may not be made explicit in undergraduate education, it is quite likely that students will have exposure to the role of emotive reasoning in the engineering design process.

Engineering education has yet to integrate the third form of reasoning that is central to engineering design decisions: intuitive reasoning. Intuitive reasoning is a part of all decisions (Khatri & Ng, 2000). Generally, intuitive approaches to decision-making are easily accessible, coming rapidly and without effort (Kahneman, 2003). Intuition has also been defined as "an implicit process which leads to feelings about a course of action or behavior the reasons for which are not easily verbalized" (Sadler-Smith & Shefy, 2004, p. 2). A detailed analysis of how engineering design decisions are made revealed that professionals map their own intuition onto the more formal, or rational, evaluation of design options (Girod, Elliott, Burns, & Wright, 2003). In some roles potentially filled by engineers, such as executive management, intuitive reasoning is seen as just as important as rational analysis for decision-making (Sadler-Smith & Shefy, 2004). While some perspectives have emphasized intuitive approaches as a valuable part of expert ability (Klein, 2008; Phillips, Klein, & Sieck, 2004), others have revealed them as a fallible shortcut based on heuristics and bias (Tversky & Kahneman, 1975). In other words, while expert intuition may allow for elegant decision-making, an abundance of experimental psychology and social science research provides thorough evidence that intuitive reasoning may utilize cognitive biases such as anchoring bias, availability bias, and implicit bias. The use of tools and formal processes can reduce the impact of these biases, but they are inherent to human cognition. Burke & Miller (1999) posit that decision-makers need to iterate between intuitive and rational strategies for effective decision making.

Working from the assumption that intuitive reasoning can and should be integrated into engineering education (per argument presented above), this work provides a baseline of how intuition has been defined and portrayed, drawing on literature from the field of management. The field of management was chosen due to its focus on strategic decision making, which shares many primary characteristics with engineering decisions. For example, managers often make decisions that are complex, ill-structured and time-dependent. Similarly, engineers need to make decisions in ill-structured contexts where information is never complete, issues are complex (societal, political, etc.) and deadlines exist. This baseline is useful so that we can begin to understand how to translate existing work around intuition into recommendations for engineering educators to teach decision making in more realistic and robust ways.

Research Questions

This project was driven by the following research questions:

1. How does extant literature in management characterize intuition?
2. How does extant literature in management portray the value of intuition?

Method & Coding

To answer our research questions, we conducted a systematic review utilizing recommendations from PRISMA (2018) to guide our methodological decisions. The method and exclusion criteria we used are summarized in Figure 1. To establish a reasonable scope for this project, we limited our database searching to ERIC and PsycINFO. ERIC is a widely-used database for full-text education literature and resources, which is well aligned with our research in engineering education. PsycINFO was also searched because of its vast coverage of peer-reviewed behavioral and social science content. While this did potentially exclude some valuable articles, we felt it necessary due to the limitation on our time and resources to conduct this work, which Borrego and colleagues (2015) identify as a common challenge of conducting systematic reviews. After performing some preliminary searches, we converged on utilizing EBSCOhost to simultaneously search ERIC and PsycINFO for keywords "intuition" and "decision-making." This resulted in 1414 possible sources for review. Next, we added filters to limit the search to materials that were peer reviewed, published in academic journals, and written in English, which reduced the number of possible articles to be included in our systematic review to 740.

At this point, the top six classifications of articles that met our inclusion criteria were as follows:

1. Cognitive processes
2. Management & management training
3. Personality traits and processes
4. Professional personnel attitudes and characteristics
5. Industrial and organizational psychology
6. Health & mental health services

We then limited our review to those classified as 'management and management training.' Again, this decision was made because managers are often required to make strategic decisions, which share characteristics with engineering decisions. In addition, we were interested in understanding how intuition was characterized and portrayed in the context of real-world decision making, rather than as an isolated cognitive process or aspect of a person's personality. This step of adding an additional exclusion criterion resulted in 70 papers eligible for review. After removing duplicates, we arrived at 68 total papers under consideration.

Next, the abstracts of all 68 of these sources were screened for relevance by the first author. The screening criteria was whether or not the abstract conveyed that the study focused on intuition as a major construct, with an emphasis on the use of intuition and/or the role of intuition in decision making. This screening resulted in a total of 35 articles for full review to address our research questions. The research team worked together to read each article in full and synthesize the contributions of these articles to answer the posed research questions. Upon full review, five additional articles were removed from consideration due to a focus on a central concept other than intuition, such as emotion, common sense, executive skills, or speed of decision-making (Fenton-O'Creevy, Soane, Nicholson, & Willman, 2011; Jensen, 2009; Ow & Morris, 2010; Wally & Baum, 1994; Zhao, 2009). One article was removed because the research team perceived that it was not of high enough quality to be included (Fomin, Alekseev, Fomina, Rensh, & Zaitseva, 2016). To conduct our qualitative review of the final 29 articles, each author read a subset of articles in full and conducted open coding on any relevant information related to our research questions. In other words, we identified within each article the ways in which the authors characterized intuition and the ways in which the authors portrayed the value of intuition. These codes were documented in a common spreadsheet, and then discussed as a research group to synthesize the themes presented here.

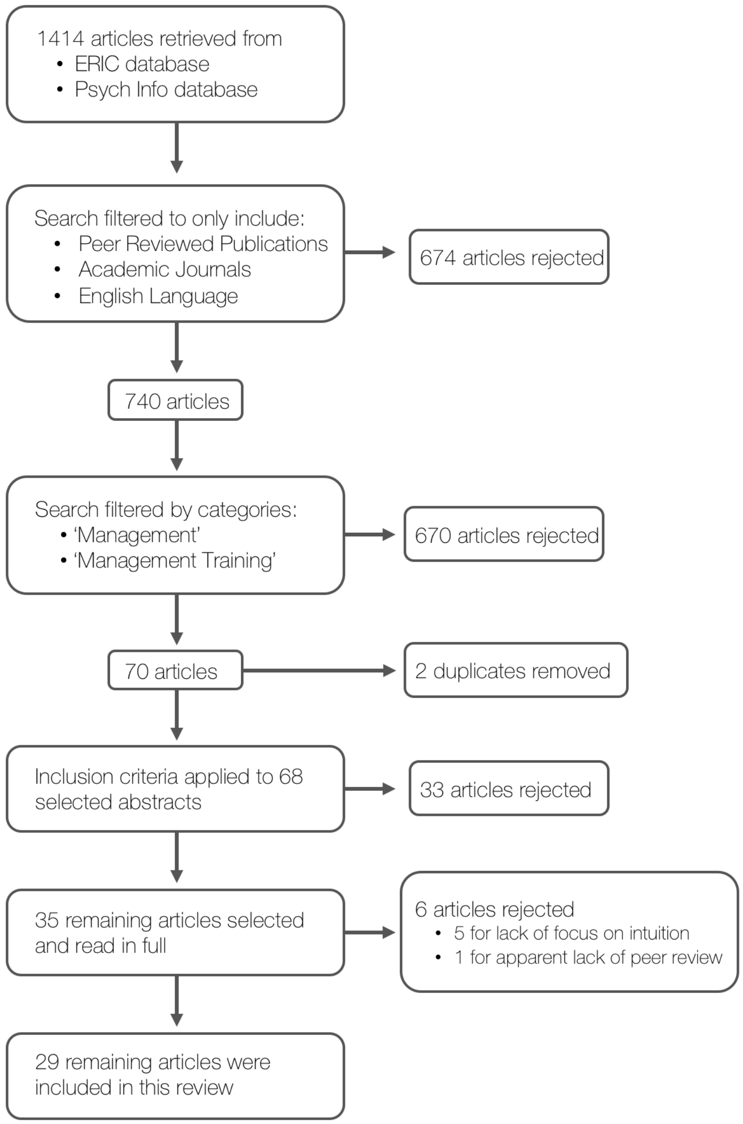

Figure 1. Method and exclusion criteria for our systematic review.

The next section presents the results of our systematic review.

Findings

We confirmed our assumption that management was an appropriate area of research and literature to draw from because of the parallels between management and engineering with respect to decision making. Within the set of articles reviewed, strategic decisions were referred to as decisions that have "significant uncertainty, little or no precedent, limited facts, numerous possible alternatives, and high cost of failure, [which] makes them ill-defined and unstructured" (Brockmann & Simmonds, 1997). We were also pleased that conducting a systematic review brought in scholarship from diverse places around the world that we may otherwise have missed. These places included Israel (Lipshitz & Shulimovitz, 2007), the United Kingdom (Dhami & Thomson, 2012; Dörfler & Ackermann, 2012; Hensman & Sadler-Smith, 2011), Sweden (Andersen, 2000, 2010), Taiwan (Kuo, 1998), Australia & Hong-Kong (Sinclair, Ashkanasy, & Chattopadhyay, 2010), and the Netherlands, Australia and South Africa (Calabretta, Gemser, & Wijnberg, 2017). In addition to answering both of our research questions through these diverse sources of literature, we also identified important differences in how scholars tried to access or measure intuition. We briefly present the different approaches here, so that readers understand the framing of the ways in which intuition was "accessed" in the studies used in our systematic review.

Ways to Access Intuition

Intuition is an internal process, which cannot be observed directly. Accordingly, the majority of the articles that we reviewed solicited information about people's use of intuition through asking them to describe their approach to decision making. For example, professionals participated in semi-structured interviews and their characterization and use of intuition was inferred from what interviewees shared about their own perspectives on decision making and decision-making behaviors (Lisa A. Burke & Miller, 2005). Additionally, other articles solicited information about people's use of intuition by having participants self-report their own habits or behavior. For example, Sadler-Smith (2016) asked participants to remember and describe an experience that used their intuition by completing prompts like, 'When I intuit…' and, 'When I have an insight I…'. Similarly, Rauf (2014) gathered perspectives on intuition through unstructured interviews, and earlier work by Sadler-Smith & Shefy (2007) had individuals write in reflective journals about their experiences learning about intuition.

In addition to what people could articulate about their use of reasoning approaches, the Myers-Briggs Type Indicator (MBTI) was a popular instrument assumed to indicate a meaningful measure of an individuals' propensity towards or likelihood of using intuition. MBTI consists of four dualistic measures of personality, which are enumerated below (Hirsh, 1998):

1. Introversion/Extroversion (the way you direct and receive energy)
2. Sensing/Intuition (the way you take in information)
3. Thinking/Feeling (the way you decide and come to conclusions)
4. Judging/Perceiving (the way you approach the outside world)

Only one article utilized all four measures of the MBTI in their study of the decision-making of managers (Hough & ogilvie, 2005). Other articles that utilized MBTI to access intuition focused on either one or both of the second and third constructs as indicative of intuition in decision-making. In the context of the MBTI (in the Jung-ian sense), intuition is about a person's preference or tendency when taking in information, and intuition is posed against sensing. Individuals who are 'Sensing' prefer to take in 'the here and now'— concrete facts. Alternatively, individuals who are 'Intuition' prefer to synthesize more general patterns and focus on projecting 'what could be' into the future. 'Thinking' and 'Feeling' are distinguished as contrasting preferences for actual decision making. 'Thinking' describes individuals who prefer to think logically about information, while 'Feeling' describes individuals who prefer to rely more heavily on their feelings as they process information for decision making. Two articles relied on only the information-processing or decision-making aspect (Thinking/Feeling) of the MBTI as important to the construct of intuition (Brockmann & Simmonds, 1997; Dane & Pratt, 2007). Alternatively, several articles utilized the combination of both the second and third constructs of the instrument to characterize an individual's level of intuition use (Andersen, 2000, 2010; Novicevic, Hench, & Wren, 2002; Vance, Groves, Paik, & Kindler, 2007). Additional work combined these same constructs into what was referred to as the Keegan Type Indicator (Andersen, 2000, 2010). Multiple articles did acknowledge that there have been some challenges to the use of MBTI as a valid instrument (Lisa A. Burke & Miller, 2005; Vance et al., 2007).

One unique method of trying to measure intuition was through the use of physiological measures. For example, one study measured skin conductance responses during engagement with high-risk games. This measure was assumed to reveal the presence of intuition because the conductance of participants' skin (increases with presence of sweat) was elevated even before the participants consciously understood the level of risk for a given game (as reviewed by (Dane & Pratt, 2007)). Another article considered intuition strictly as a theoretical concept to be modeled and subjected to mathematical manipulation (Matzler, Uzelac, & Bauer, 2014b).

RQ 1: Themes across Characterizations of Intuition

To answer our first research question, we found the ways in which extant literature in management characterized intuition. The characterization of intuition can be synthesized into four major themes, which are summarized in Table 1 and then explained in more detail in the following sections.

Table 1. Themes in how extant management literature characterizes intuition

Characterization	Summary	Sample Citations
Intuition happens rapidly and subconsciously	Authors frequently described intuition as something that cannot be articulated by the intuitor; it is something that happens subconsciously, rapidly, and in an associative manner.	(Agor, 1986; Brockmann & Anthony, 1998; Lisa A. Burke & Miller, 2005; Calabretta et al., 2017; Dane & Pratt, 2007; Hensman & Sadler-Smith, 2011; Hough & ogilvie, 2005; Kuo, 1998; Matzler, Uzelac, & Bauer, 2014a; Rauf, 2014; Rockenstein, 1988; Sadler-Smith & Shefy, 2007; Sinclair et al., 2010; Vance et al., 2007)
Intuition comes from tacit knowledge or pattern recognition	Intuition was widely characterized as relying upon one's tacit knowledge or ability to recognize patterns, which is gained through experience and recognized as expertise.	(Bennett, 1998; Brockmann & Simmonds, 1997; Lisa A. Burke & Miller, 2005; Rauf, 2014; Sadler-Smith & Shefy, 2007; Sinclair et al., 2010; Woiceshyn, 2009)

Intuition is connected to emotion	Multiple articles described intuition as involving a gut feeling, emotional reaction, or a feeling of conviction.	(Agor, 1986; Bennett, 1998; Calabretta et al., 2017; Dane & Pratt, 2007; Hensman & Sadler-Smith, 2011; Lipshitz & Shulimovitz, 2007; Matzler et al., 2014b; Rauf, 2014; Sadler-Smith & Shefy, 2007; Vance et al., 2007; Woiceshyn, 2009)
Intuition is a skill that can be developed	Nearly all articles characterized intuition as a skill that can be developed with practice. The notable outlier characterized intuition as an inherent ability.	All except (Cosier & Aplin, 1982)

Intuition happens rapidly and subconsciously

Across the vast majority of the articles reviewed, intuition was situated or described through the use of four common characteristics. The first dominant characteristic of intuition across the reviewed articles was that intuition is commonly defined as something that happens rapidly and cannot be articulated by the intuitor, or something that happens *subconsciously*. In this situation, the intuitor cannot explain how intuition led them to a decision (Calabretta et al., 2017; Hensman & Sadler-Smith, 2011; Rockenstein, 1988). This was further described as a non-conscious recognition of patterns or holistic associations (Calabretta et al., 2017; Dane & Pratt, 2007; Kuo, 1998; Rauf, 2014; Sadler-Smith & Shefy, 2007; Sinclair et al., 2010; Vance et al., 2007). Sometimes this subconscious characteristic of intuition is likened to very rapid, logical processing (Agor, 1986) or as a function of knowledge stored subconsciously (Bennett, 1998), which is seen as strictly cognitive (Lisa A. Burke & Miller, 2005). Similarly, the subconscious nature of intuition was likened to the well-established concept of System 1 (Matzler et al., 2014a). Only one article suggested that intuition could be utilized consciously by considering if-then statements or actively using schemas (Brockmann & Anthony, 1998).

Intuition comes from tacit knowledge or pattern recognition

Secondly, intuition was characterized as the development of expertise in the form of *tacit knowledge* built through experience. For example, intuition was equated with the collection of tacit knowledge, resulting in a way of knowing that can only be gained through significant experience (Bennett, 1998; Sadler-Smith & Shefy, 2007). Brockmann and Simmonds (1997) also focused on tacit knowledge, developed through experience and applicable education, and used an instrument aimed at measuring tacit knowledge to develop an understanding of how managers used intuition. The development of tacit knowledge needed for effective intuitive reasoning was described as an internal reservoir of cumulative experience and expertise (Rauf, 2014) and also as schemas (Lisa A. Burke & Miller, 2005; Woiceshyn, 2009). Relatedly, intuition can result from experience leading to the ability to holistically recognize a situation or pattern (Sinclair et al., 2010; Woiceshyn, 2009). While the characterization of intuition as a function of tacit knowledge or expertise is positive, Woiceshyn (2009) does point out that reliance on schemas can lead to bias in novel situations. In general, intuition is characterized as something that is developed over time and only available to experts.

Intuition is connected to emotion

The third key characteristics used to describe intuition was its affective nature or *connection to emotion*. For example, intuition might be associated with feelings or emotions such as a hunch, gut-feeling or vibes (Agor, 1986; Bennett, 1998; Hensman & Sadler-Smith, 2011; Sadler-Smith & Shefy, 2007; Vance et al., 2007; Woiceshyn, 2009). In a study of how loan officers made decisions conducted by Lipshitz and Shulimovitz (2007), the participants described the dominant role of their gut feelings in nearly every single case (22 of 23 cases) of their professional decision-making. Multiple authors described the result of an intuitive decision as an "affectively charged judgement" (Calabretta et al., 2017; Dane & Pratt, 2007). An intuitive decision was also characterized as associated with a feeling of conviction or rightness (Matzler et al., 2014b) or urge to do something (Rauf, 2014).

Intuition is a skill that can be developed

Finally, the overwhelming majority of the articles seemed to infer that the use of intuition, however it was defined, was a skill that could be learned and developed. Kuo (1998) defines intuition directly as a cognitive ability. In contrast, only two articles described intuition as a unique individual "power," an inherent ability to "outguess" others (Cosier & Aplin, 1982), or an ability conferred upon us by natural selection (Sadler-Smith & Shefy, 2007). Different recommendations are made on how to develop intuitive abilities such as quieting the mind (Rockenstein, 1988) or being attuned to personal feelings (Sadler-Smith & Shefy, 2007).

RQ 2: Themes across Portrayals of Value of Intuition

All of the reviewed articles portrayed intuition as valuable, which isn't surprising; it is often the lack of attention to intuitive reasoning that indicates a belief that intuitive reason is of little or no value. For our second research question, we found that the ways in which extant literature in management portray the value of intuition included the following themes: secondary to rational approaches, specific to context or type of decision, potentially not publicly recognized as trustworthy, and linked to higher quality decisions.

Table 2. Themes in how extant management literature portrays the value of intuition

Portrayal of Value	Summary	Sample Citations
Intuition is valuable when used in combination with rational approaches	Nearly all authors portrayed intuition as a supplemental, supporting, or secondary approach that was used in combination with rational approaches.	(Agor, 1986; Bennett, 1998; Brockmann & Anthony, 1998; Lisa A. Burke & Miller, 2005; Calabretta et al., 2017; Dane & Pratt, 2007; Dhami & Thomson, 2012; Ford & ogilvie, 1997; Kuo, 1998; Matzler et al., 2014b; Sadler-Smith & Shefy, 2007; Sinclair et al., 2010; Vance et al., 2007)
Intuition is valuable for certain types of decisions or in specific contexts	Many authors specified types of decisions or contexts for decision making in which intuition was valuable.	(Agor, 1986; Bennett, 1998; Brockmann & Simmonds, 1997; Lisa A. Burke & Miller, 2005; Dane & Pratt, 2007; Dhami & Thomson,

		2012; Dörfler & Ackermann, 2012; Ford & ogilvie, 1997; Hensman & Sadler-Smith, 2011; Kuo, 1998; Lipshitz & Shulimovitz, 2007; Matzler et al., 2014a, 2014b; Rauf, 2014; Sadler-Smith & Shefy, 2007; Sahm & von Weizsäcker, 2016; Vance et al., 2007)
Intuition may not be publicly recognized as valuable	Cultural norms may limit the public acceptance of a decision made intuitively, especially by limiting those who can be trusted to use their intuition to those perceived as experts.	(Dörfler & Ackermann, 2012; Hensman & Sadler-Smith, 2011; Kuo, 1998)
Intuition results in high-quality decisions	Several studies actually linked the use of intuition to the ability to make high quality decisions.	(Sahm & von Weizsäcker, 2016)

Intuition is valuable when used in combination with rational approaches

An important take away from the articles in this review is that while intuition is regarded as valuable, it is portrayed as something that must be used in combination with rational approaches, due to its fundamental difference (Bennett, 1998; Calabretta et al., 2017; Vance et al., 2007). Intuition is not viewed as something that is valuable if used in isolation, Brockmann and Anthony (1998) liken the use of intuition alone to ignorance! Instead, rational and intuitive decision-making approaches are considered as two separate and competing dimensions that can be used to complement one another (Ford & ogilvie, 1997; Matzler et al., 2014b; Sadler-Smith & Shefy, 2007) or that can be combined for quasi-rationality (Dhami & Thomson, 2012). Another perspective was that rational and intuitive approaches are separate, but can be considered as two aspects of the same multi-faceted construct, which should be studied as complementary rather than mutually exclusive (Kuo, 1998; Sinclair et al., 2010).

Intuition is valuable for certain types of decisions or in specific contexts

Intuition is portrayed as useful for specific types of decisions or under certain conditions, during specific times or phases of a decision-making process, or by certain people. First, intuition is often considered useful when decisions are being made in a context that is unstructured, ambiguous, turbulent or when the decision maker cannot access the 'data' required for rational methods (Bennett, 1998; Brockmann & Simmonds, 1997; Dane & Pratt, 2007; Dhami & Thomson, 2012; Ford & ogilvie, 1997; Vance et al., 2007). Intuition is also valuable when time is limited or risk is low (Dhami & Thomson, 2012; Hensman & Sadler-Smith, 2011; Lipshitz & Shulimovitz, 2007). Dane and Pratt (Dane & Pratt, 2007) argue further that intuition is effectively employed when the task requires judgmental decisions (e.g. political, ethical, etc.) rather than intellective decisions (e.g. possess definite criteria, rules or relationships). The use of rational methods as only superior for intellectual tasks is echoed by Rauf (2014). The size of a company and presence of rules or procedures can influence the use of intuition (Matzler et al., 2014a).

Second, intuition is portrayed as valuable at particular times in the decision-making process. This includes early or creative stages such as exploring or considering new possibilities, developing new products or identifying new markets (Brockmann & Simmonds, 1997; Dörfler & Ackermann, 2012; Kuo, 1998; Matzler et al., 2014b). Intuition is also portrayed as valuable towards the end of a decision-making process, in the form of a gut check (Brockmann & Simmonds, 1997). While these early and late stages of the process may rely on intuition, the intermediate stages are governed by reason (Sahm & von Weizsäcker, 2016).

Intuition may not be publicly recognized as valuable

Third, the issues of public recognition of the value of intuition was discussed by some of the articles. For example, intuition may only be credible when made by individuals who have the appropriate level of domain knowledge and for given task characteristics (Dane & Pratt, 2007; Kuo, 1998). Individuals who are recognized for their expertise may be more trusted to use their intuition effectively (Dhami & Thomson, 2012; Dörfler & Ackermann, 2012; Hensman &

Sadler-Smith, 2011). This can interact with gender norms, as women in the workplace may be less likely to attribute their decision making to the use of intuition (Lisa A. Burke & Miller, 2005). On a related note, managers may utilize intuition yet feel the pressure to defend their decisions more logically. Although decisions may always utilize intuition to a certain degree, decision makers often rationalize their decisions after the fact (Novicevic et al., 2002). Agor (1986, p. 15) quotes a participant describing their own experiences in the workplace, "sometimes one must dress up a gut decision in 'data clothes' to make it acceptable or palatable, but this fine tuning is usually after the fact of the decision."

Intuition results in high-quality decisions

One study actually had managers participate in simulations of decision making and then evaluated the quality of those decisions. They found that mangers who ranked high in intuitive decision-making styles (as measured by MBTI) actually did make decisions that were of higher quality than those who did not have intuitive decision-making preferences (Hough & ogilvie, 2005). Additionally, researchers who conducted in-depth interviews with individuals who had made significant scientific advances, such as Nobel Laureates, concluded that "we are inclined to believe that no significant creative result has been achieved in any other way than by means of intuition" (Dörfler & Ackermann, 2012, pp. 555-556). Based on a strictly theoretical model and manipulation of intuition, an additional article concluded that intuitive decision-making should result in a higher "net utility" than rational reasoning (Sahm & von Weizsäcker, 2016).

<u>Limitations</u>

Our study is subject to several limitations. We did not search every available data base, which limited the scope of the articles reviewed and synthesized in this review. We also limited our subject area to management, which excluded potentially rich fields related to intuitive decision making such as cognitive science or behavioral economics. During the research process, we did not calibrate the process for screening the abstracts of articles, so this process relied on the bias and decisions of the first author alone. In addition, we didn't calibrate our coding of the articles or attempt to calculate an interrater reliability. We did engage iteratively in discussions to review and revise the coding as well as the themes synthesized from the coding process. Beyond eliminating one article due to a lack of perceived quality, we did not develop a systematic way of reporting the perceived quality of all of the articles included in our review.

Discussion & Recommendations

As demonstrated by the recently-revised language for undergraduate engineering degree program accreditation, engineering graduates are expected to be able to demonstrate some form of 'engineering judgement' when making decisions as professionals. With an understanding of the intricacy of engineering decisions, which are complex, ill-structured, and bound by deadlines, it is unrealistic *not* to recognize the role of intuition in engineering decision making. However, the engineering education community does not yet have a clear way of understanding, studying, or integrating the use of intuitive reasoning into our undergraduate education. Our findings provide a contribution to the literature by generating a baseline of themes for ways in which intuitive reasoning has been characterized and portrayed as valuable by scholars. These themes can directly inform how we can begin to explicitly include intuitive reasoning within undergraduate education. We provide some preliminary ideas about how engineering educators might work intuition into their framework for teaching decision making.

To begin, the themes for characterizing intuition presented in Table 1 provide a great summary for engineering educators wanting a framework to talk about intuitive reasoning or to introduce the concept of intuition to their students. The first three characterizations provide a common way to understand what intuition is or how to recognize it in our own thinking. To put it simply, intuition happens rapidly and without effort, it often comes with the development of expertise and it is commonly experienced as an emotion or feeling. These simple characterizations synthesized from intuition scholars are helpful because they reduce some of the fuzziness around the construct and put it in terms of rapid processing or expertise, which are already valued in engineering culture. As a concrete example, engineering educators can ask students to make an initial 'guess' about how a problem solution might turn out or to do a 'gut check' on the final solution they arrive at. This draws attention to the ways in which repeated experiences solving rule-based problems or making decisions is intended to build expertise that allows a person to have a ‘feel’ for things. These practices have the potential to heighten students’ awareness of the significant role that intuition plays in their own thinking (rather than ignore or dismiss it). The final theme in Table 1 is that intuition is a skill that can be developed. This strengthens the argument that engineering students should not only be aware of the nature and role of intuition, but they should also be encouraged to pay attention to areas of their lives where they already have expertise (likely not engineering) and how that informs their decision-making. Because undergraduate students are not developing expertise, another option to demonstrate the role of intuitive reasoning in engineering would be to encourage engineering practitioners who engage with students about their experiences with real-world decision-making to include explicit discussion of how they utilize intuitive reasoning at work. Instructors could also explicitly model their own use of intuition in their respective areas of expertise.

With respect to the themes presented in Table 2 for the ways extant literature portrays intuition as valuable, the first theme is that intuition scholars recognize the benefits of intuition as a form of reasoning to be combined with rational approaches. We want to be clear that we are not arguing for the use of *only* intuitive reasoning for engineering decisions, but rather a more realistic emphasis on the limits of rational reasoning and a more holistic picture of engineering decision-making as a synergistic combination of intuitive and rational reasoning. The second theme provides insight into the types of decisions or context where intuition is most apparent and necessary. These include complex and real-world decisions where the decision maker would never be able to get all the data needed to make the decision with strictly rational methods. As such, we recommend that engineering educators consider where in their curriculum students are provided opportunities to engage in such decisions (e.g. cornerstone or capstone design) and purposefully integrate intuitive reasoning into these spaces. Our synthesis of extant literature revealed that intuition is particularly important in both early, exploratory phases of a decision-making process and as a tool for a final gut or ethics check. So, as a concrete recommendation, design educators can encourage their students to be in tune with their gut reactions or feelings both during the ideation stage of a design project as well as when the team transitions into convergent thinking. For example, if students are asked to utilize a decision matrix to map weighted user needs to their initial design concepts, an instructor could ask students if the ‘best’ design based on the matrix output was what they expected. If not, this is an opportunity to talk about how their subconscious synthesis, or intuition, may be including important factors that are not included in the matrix as a rational tool. The key is that teams can then iterate on their rational reasoning until it better aligns with their intuitions or the intuitions of experts.

We would like to note that while we encourage the portrayal of intuition as valuable, it is also important to also recognize that just like rational tools, it has limits. Within our review, Woiceshyn (2009) and Kuo (1998) included acknowledgements, rooted in the work of cognitive scientists, that overreliance on intuition can lead to bias or errors. Intuition is largely viewed as something that can benefit the decision-making process when used systematically and iteratively in support of rational decision-making methods. However, it will be important that students understand how the use of intuition or pattern recognition can be a source of bias. In addition, others may not recognize intuition as trustworthy, so it is critical that engineers iterate between different forms of reasoning rather than just relying on rational or intuitive reasoning alone.

A challenge for both undergraduate engineering and the engineering workplace is to build the inherent use of and value of intuition into the culture. Unless we as engineering educators acknowledge that engineering decisions have a judgmental component, we will continue to produce engineering graduates that are overly reliant on rational tools alone. Rational thinking is indeed useful and valuable for many aspects of engineering, particularly analytical tasks, but it is of limited use for the more complex design decisions that engineering professionals make when working to solve real-world problems.

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