STUDIES IN ENGINEERING EDUCATION

Theorizing Engineering Judgment at the Intersection of Decision-Making and Identity

THEORY

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VIRGINIA TECH PUBLISHING

ABSTRACT

Engineering judgment is critical to both engineering education and engineering practice, and the ability to practice or participate in engineering judgment is often considered central to the formation of professional engineering identities. In practice, engineers must make difficult judgments that evaluate potentially competing objectives, ambiguity, uncertainty, incomplete information, and evolving technical knowledge. Nonetheless, while engineering judgment is implicit in engineering work and so central to identification with the profession, educators and practitioners have few actionable frameworks to employ when considering how to develop and assess this capacity in students. In this paper, we propose a theoretical framework designed to inform both educators and researchers that positions engineering judgment at the intersection of the cognitive dimensions of naturalistic decision-making, and discursive dimensions of identity. Our proposed theory positions engineering judgment not only as an individual capacity practiced by individual engineers alone but also as the capacity to position oneself within the discursive community so as to participate in the construction of engineering judgments among a group of professionals working together. Our theory draws on several strands of existing research to theorize a working framework for engineering judgment that considers the cognitive processes associated with making judgments and the inextricable discursive practices associated with negotiating those judgments in context. In constructing this theory, we seek to provide engineering education practitioners and researchers with a framework that can inform the design of assignments, curricula, or experiences that are intended to foster students' participation in the development and practice of engineering judgment.

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KEYWORDS:
engineering judgment; engineering identity; discursive identity; identity production; professional communication; decision-making

TO CITE THIS ARTICLE:
Francis, R. A., Paretti, M. C., & Riedner, R. (2022). Theorizing Engineering Judgment at the Intersection of Decision-Making and Identity. *Studies in Engineering Education*, 3(1): 79–98.

1. INTRODUCTION

Starting with the 2019–2020 accreditation cycle, ABET (2018) added the ability to "use engineering judgment to draw conclusions" (p. 6) as an outcome for engineering graduates. Yet while the concept of judgment has been implicit in engineering work for many years, educators and practitioners alike have few actionable frameworks to employ when considering how to develop and assess this capacity in students. In fact, in one of the more frequently cited examinations of engineering judgment, Michael Davis (2012) noted that "so little has been written about judgment" (p. 791) and argued that "teachers of engineering [...] might do a better job if they were clearer about what the judgment they teach is and how it can be taught" (p. 791). But in the decade since Davis made his "Plea for Judgment" (as his article is titled), little research has emerged in engineering education to address this need, and scholars and educators alike are left with few strategies for studying, teaching, or assessing engineering judgment. To that end, recent findings from both other scholars and our own research suggests that engineering judgment may be a key learning outcome of writing instruction embedded in engineering courses, in which the process of developing reports, presentations, and posters about ongoing projects creates contexts that require students to exercise judgment and justify a range of decisions. In his ethnographic work on student design teams, for example, Weedon (2019) identifies the ways in which judgments are constructed and negotiated rhetorically through words, texts, gestures, and figures, and he explicitly positions engineering judgment as "a rhetorical competency" rather than simply a technical one. Similarly, our empirical research on engineering student writing finds that students are continuously making complex judgments across a full range of complex technical, social, and rhetorical dimensions (Francis et al. 2021; Francis et al. 2021, 2022).

These links between judgment and communication in engineering align with broader research on engineering practice that emphasizes the fundamentally social, context-dependent nature of engineering work (Bucciarelli 2001; Trevelyan 2010, 2014b; Wilde and Guile 2021). The context in which engineers work is characterized by ongoing complex social interactions among and between interprofessional teams; often-competing interdisciplinary standards of validity and knowledge exchange; and both espoused and implicit organizational values, goals, norms, and objectives. Practicing engineers participate in and construct acts of judgment amid these complex situational dynamics, yet there is limited research on the ways engineering education can help students cultivate the skills and capacities needed to successfully navigate these dynamics and exercise engineering judgment in the workplace. Moreover, research by Ford et al. (2021) and Lutz and Paretti (2021) on new graduates' transitions from school to work highlights the significant context gap as students moves from the structured, close-ended, individualized world of engineering courses to the collaborative, contingent, open-ended, and contextual world of engineering work. These context gaps further complicate graduates' ability to enact engineering judgment as they move from school to work, pointing to the need for explicit, intentional pedagogies to better prepare students to construct and negotiate engineering judgments that are responsive to these interdependent dynamics.

Given both the limited research on engineering judgment broadly and the emerging intersections between engineering judgment and writing, we draw on several strands of existing research to theorize a working framework for engineering judgment that considers both the cognitive processes associated with making judgments and the (simultaneous, inextricable) discursive practices associated with negotiating those judgments in context. By judgment, we mean the interpretation and evaluation of options in a situation or issue characterized by ambiguity, uncertainty, and/or incomplete information. By engineering judgment, we mean judgments made or actions taken in the context of engineering work, in which individuals or groups draw on the tacit or explicit knowledge, common practices and conventions, and/or norms and expectations of the field to render their judgments. Notably, research on judgment is often embedded in the broader research on decision-making, where judgment and choice are closely linked. While the boundaries between judgment and choice are often contested in the decision-making literature, here we align with scholars who conceptualize judgment as the evaluative assessment of options, and choice as the selection of a given option (see Gonzalez 2017).

In building this framework, we drawn on two primary domains (discussed in detail in Sections 3 and 4, respectively): 1) research on decision-making, with a focus on cognition, and 2) research on identity, with a focus on discursive identity. While there are potentially a number of different domains that could be used to theorize engineering judgment, we selected these in particular based on both existing research on judgment and current issues in engineering education. First, while research on judgment in engineering education is limited, the work that does exist consistently links judgment to decision-making in ill-structured, ambiguous contexts. At the same time, the broader scholarship on judgment often emerges within research on decision-making, particularly in the cognitive sciences. This focus on cognitive processes in decision-making research intersects with current work in engineering education on misconceptions (Streveler et al. 2014), conceptual understanding (Bornasal et al. 2018; Montfort et al. 2009; Streveler et al. 2008), and metacognition (P. Cunningham et al. 2017; P. J. Cunningham et al. 2018; McCord & Matusovich 2019) that lay critical foundations for course and curriculum design.

Second, recent research on naturalistic decision-making in teams (Mosier et al. 2018), coupled with work by Weedon (2016, 2017, 2019) and House et al. (2014) as well as our own research on engineering judgment (Francis et al. 2021; Francis et al. 2021, 2022), points to the ways that within engineering, judgment is not solely an individual cognitive act, but rather a discursive negotiation involving the ability to be recognized – by one's self and others – as someone legitimately able to exercise judgment. This recognition aligns with Gee's (2000) definition of discursive identity, which in turn intersects with studies highlighting the ways in which engineering identity is discursively constructed and not equally available to all students (e.g., Tonso 2006).

In light of this research, discussed in more depth in subsequent sections, we propose a theorization of engineering judgment that integrates cognitive frameworks for decision-making with discursive frameworks for identity in ways that are relevant to the contexts of engineering work. Figure 1 captures the key pieces of this theorization, illustrating the ways that enacting engineering judgment involves the interplay of cognitive processes associated with decision-making and culturally framed discursive processes associated with identity development, interacting with

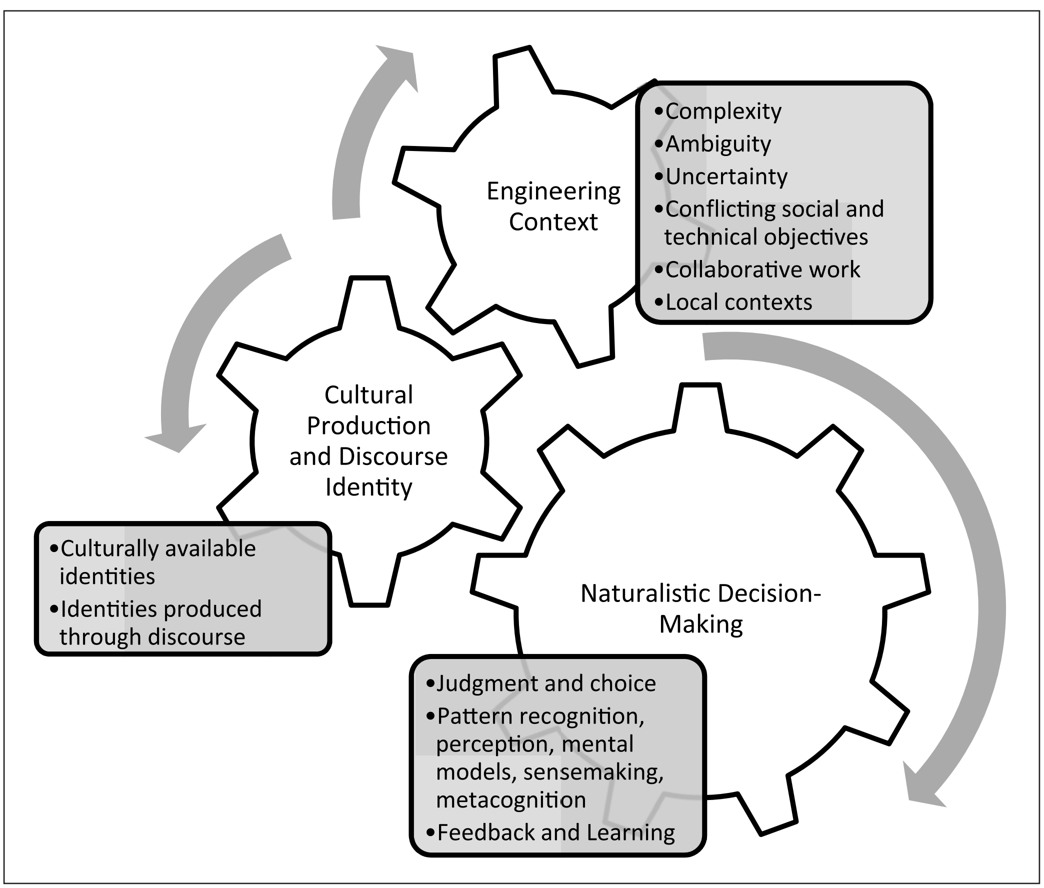

Figure 1 Elements of our theory of engineering judgment. We define engineering judgment as a holistic participatory capacity integrating the technical and social context, the cultural and discursive production of professional identities, and naturalistic decision-making processes. Decision-making models and related cognitive processes are explored in Section 3 while discursive identity and cultural production are explored in Section 4.

the context of engineering work. Following a brief background on current research related to engineering judgment (including the context of engineering work), we unpack the two primary components of the framework.

Notably, while we focus on building a framework to help educators design educational experiences that can help students develop engineering judgment, the research on judgment and decision-making includes numerous studies of professionals that helps define the "target" of those educational experiences. At the same time, practicing professionals are experts who have built their capacity for judgment over time through experience, and a significant body of literature addresses the development of such expertise (see Litzinger et al. 2011, for a useful review of this literature as related to engineering). While we have not included the broader research on expertise in our initial framework, instead choosing to focus specifically on salient aspects of decision-making and identity, the literature on expertise can and should play a key role in follow-up studies extending and applying our proposed framework.

2. BACKGROUND: JUDGMENT IN ENGINEERING EDUCATION RESEARCH

Before turning to the two domains anchoring our proposed framework, we begin with a brief review of the ways engineering judgment has been discussed and defined within the field to date to situate our work and establish the need for a more concrete conceptualization of judgment to inform engineering education practice and research. In his 2012 "Plea for Judgment," Davis argues that "judgment is central to engineering" (p. 789), and indeed, professional judgment is a ubiquitous, if undefined, feature in several landmark studies on engineering practice (e.g., Sheppard et al. 2008, Trevelyan 2010). Yet, prior to ABET's newest student outcomes, it rarely featured in expectations of new graduates. It does not appear, for example, in the National Academy's list of attributes of engineers in 2020 (National Academy of Engineering 2004). Although judgment and decision-making were included in early versions of the Engineer Profile delineating expected roles and behaviors for new graduates empirically developed by Davis et al. (2005), neither judgment nor decision-making appear in the final profile. Similarly, although Trevelyan's own workplace research highlights the role of judgment, it does not appear in the "classification of engineering activities and specialist knowledge" delineated in his book *The Making of an Expert Engineer* (2014a). At the sub-discipline level, however, the term does appear within the descriptions of several outcomes in the most recent *Civil Engineering Body of Knowledge* (Civil Engineering Body of Knowledge 3 Task Committee 2019), and the concept of engineering judgment features prominently in geotechnical engineering in particular (Vick 2002). Even when the term does appear, however, it remains largely undefined in these broad efforts to scope and explain engineering work.

Engineering judgment is equally scarce – and ill-defined – in empirical engineering education research. A November 2021 search of the *Journal of Engineering Education*, for example, returns only a single article with the term "judgment" (search term: judg*) in the title or keywords – Jesiek et al.'s (2020) work on situational judgment as part of global engineering competency. A parallel search in the *European Journal of Engineering Education* also yielded only a single citation, which focused on using the process of adaptive comparative judgment in design pedagogy (Strimel et al. 2021). Consistent with the presence of judgment in the *Civil Engineering BOK*, the *Journal of Civil Engineering Education* (formerly *Journal of Professional Issues in Engineering Education and Practice*) does include some empirical research studies related directly to engineering judgment. For example, MacRobert examines active learning as a mechanism for developing engineering judgment, which he defines by explaining that "the terms 'common sense' and 'sense of proportion' are essentially interchangeable with the term 'engineering judgment'" (MacRobert 2018, p. 050180091). MacRobert also cites earlier work by Vick that defines engineering judgment as "a sense of what is important" (MacRobert 2018, p. 050180091). While such phrases may help build a generalized sense of what engineering judgment might mean, they are less useful to educators seeking to design and assess educational experiences to help develop this capacity, or to researchers seeking to study its development in students.

Some empirical work also appears in the proceedings of the annual ASEE conference that does begin to provide more concrete definitions. Recently, for example, in their study explore the use of inquiry-based learning to develop engineering judgment, Bruhl et al. (2017) define engineering judgment as "the ability to recognize and/or predict, through a combination of intuition, insight and experience, the probable outcome of an analysis, design or process" (p. 3). In a study using modeling activities to develop judgment, Swenson et al. (2019) offer a more expansive definition drawn from ethnographic research by Gainsburg in civil engineering (Gainsburg 2006, 2013; Gainsburg & Gainsburg 2007). Focusing on structural engineers, Gainsburg identified eight categories of engineering judgment that range from "determining what is a good or precise enough calculation or estimation" to "determining appropriate uses of technology tools" to "discretizing (grouping elements to reduce the number of types to be designed)" (cited in Swenson et al. 2019, p. 4). Weedon (2016; 2017; 2019), who studied engineering judgment in the context of communication in undergraduate design teams, offers yet another definition. Synthesizing the scant extant literature, Weedon argues that prior work treats engineering judgment as "an ability beyond mere calculation that is principally about applying scientific data to contingent circumstances" that "is almost always an individual and cognitive capacity" (2019, p. 165). Drawing on ethnographic research with student design teams, Weedon expands that definition to position judgment as "a rhetorical capacity to expand engineers' sense of a situation to understand the ramifications of action" (p. 165) as well as "the ability to rhetorically shift or invent standards and considerations in contingent situations" (p. 174).

Apart from empirical studies, definitions of engineering judgment have also emerged from philosophers – most notably the often-cited plea from Davis (2012), and more recently from McLauglin (2021) in the recent book *Engineering and Philosophy*. Davis, looking at range of professional fields, including engineering, by his own admission does not actually define professional judgment, apart from noting that it is both "a *disposition* (including the ability) to *act* as competent members of the discipline act" (p. 790) and "not wholly objective" (p. 791). He differentiates professional judgment from constructs such as value judgment (akin to ABET's conception of informed judgment), discretion, and the Greek concept of *phronesis*, which he translates loosely as "practical wisdom" (p. 801). McLaughlin, in contrast, takes up *phronesis* as the starting point for a definition of engineering judgment, and iterates through a series of philosophical arguments to arrive at the following definition:

> Engineering judgment is a value optimizing rational quality, involving conscious deliberation, tacit recognition and any other plausible problem-solving aid, concerned with determining and commanding action for making and doing things in relation to whether they are good and bad for human beings. Although engineering judgment requires general good judgment regarding all the duties within the domain of the engineering profession, the type of judgment unique to engineering regards the use of mathematical and scientifically derived principles applied to real world situations to solve problems with a minimum of undesirable unintended results. (p. 216)

While McLaughlin's and Davis' conceptions, like those of MacRobert and Vick noted earlier, offer a useful philosophical starting point, they do not provide operationalized constructs that easily inform either research or teaching, learning, and assessment. At the same time, the varying definitions in existing empirical research in engineering education suggest that the field still lacks consensus on concrete alternatives that might be shared across studies or leveraged to develop teaching practices and meaningful assessments. To that end, in this paper we offer a conceptual framework that seeks to integrate the cognitive decision-making processes underpinning current work by Bruhl et al. (2017), Swenson et al., and others, with recent conceptualizations of engineering judgment as a communicative act in work by Weedon (2017, 2019), Francis et al. (2021), and others.

In building our framework, we follow the work of Bruhl et al. (2017), Swenson et al. (2019), Weedon (2019), and others, to focus on the processes of analyzing and interpreting data and contexts to predict and evaluate potential outcomes. Implicit in these processes are not only technical capabilities, but underlying value judgments intertwined with engineering ethics. As with the concept of expertise, the extensive research on engineering ethics and ethical judgment, though outside the scope of our present work, represents another key area for future work.

3. DECISION-MAKING, COGNITION, AND THE CONSTRUCTION OF JUDGMENT

Engineering judgment in practice involves decision-making, that is, the evaluation and selection of courses of action from among multiple alternatives. We thus begin our theorization by turning to decision-making research that links judgment to choice and connects both to several inter-related cognitive processes. Research on the cognitive processes related to judgment and choice arises from the domains of behavioral economics and cognitive psychology, but it is also informed by studies of decision-making in control engineering, human factors, and ecological psychology, with much of the research focused at the individual level (Gonzalez 2017). As Gonzalez (2017) notes in her review of cognitive science research on decision-making, while the boundaries between judgment and choice are often contested, classical models of decision-making focus on two processes, typically referred to as judgment and choice, where judgment "involves evaluating the merits of and preferences for different alternatives" (p. 1) and choice is the actual selection of a specific alternative. Both judgment and choice can be seen as cognitive processes that are in turn constructed from a range of underlying processes including but not limited to perception, memory, recognition, attention, feedback, and learning. These processes either precede judgment or follow choice. These processes also help researchers to understand how individuals perceive situations that require judgment or choice, recognize similarities to and differences from other situations, receive and integrate feedback based on the outcome of the choice, and learn resulting from the processing of the feedback.

CLOSED-LOOP AND NATURALISTIC DECISION-MAKING MODELS

Two broad theoretical perspectives in this realm are particularly salient to understanding the cognitive processes associated with engineering judgment: closed-loop decision-making and naturalistic decision-making (NDM). We selected these models because they are particularly relevant to judgment in engineering contexts. Closed-loop models of decision extend "rational actor" or "subjective expected utility" models widely taught and used in engineering applications by explicitly accounting for the ways learning and feedback influence decision-makers' preferences and objectives. Therefore, closed-loop models of decision-making are helpful in representing the iterative nature of decisions in engineering practice, where feedback from clients, prototyping, testing, or other sources inform subsequent decisions. At the same time, closed-loop models rely on theoretical assumptions implied by the subjective-expected utility paradigm that may not represent how engineers make decisions in real-world contexts due to both well-documented departures from rational behavior (Kahneman & Tversky 1979; Tversky & Kahneman 1981) and the complexity of high-stakes decision contexts (Mosier et al. 2018). Naturalistic models, on the other hand, are useful because in their attention to context, they more fully account for the open-ended, ambiguous, ill-defined nature of the engineering work and the contexts in which engineers must enact judgment (e.g., Bornasal et al. 2018; Jonassen 2014). To help contextualize the key cognitive process in our framework, we provide a brief review of these approaches; for additional details, see the literature reviews by Gonzalez (2017) on cognitive science research on decision-making and Mosier et al. (2018) on naturalistic decision-making. Both the closed-loop and naturalistic approaches from cognitive psychology offer counterpoints to models developed in economics research that emphasize rationality and focus on open-loop processes in which there is no feedback based on decision outcomes. Open-loop decision models were originally developed to study decisions for games of chance and require complete knowledge of the environment, objectives, and outcomes of available choices a priori. Moreover, since open-loop models assume complete knowledge about relevant information, these models do not prioritize learning from experience. As a result, open-loop models, though they resemble some of the formalized models of decision matrices used in engineering design education, are less useful in understanding situations characterized by ambiguity, uncertainty, or high stakes scenarios that may be contextually unique – that is, the kinds of situations engineers encounter at work (e.g., Jonassen 2014; Trevelyan 2010; Trevelyan & Williams 2018). Open-loop models do not account for what researchers refer to as *dynamic decision-making* (DDM). DDM is "the process of making multiple, repeated, or sequential choices in conditions that evolve over time either as a result of previous decision, with inaction, or spontaneously from the change occurring in the environment as time passes" (Gonzalez 2017, p. 11). That is, DDM is not a single decision made once and then left, but rather an ongoing series of connected decisions in context. DDM more accurately represents the kinds of decisions professionals make in the course of their work, including the kinds of decisions engineers make throughout processes such as design, troubleshooting, maintenance, and forecasting (see, for example, descriptions of engineering practice by Trevelyan, e.g., Trevelyan 2014a; Trevelyan & Williams 2018; Jonassen et al. 2006; Jonassen 2014; Jesiek et al. 2021; Stevens et al. 2014). Design, for example, is not the result of a single decision but rather a series of decisions and interactions among designers and stakeholders that move through scoping, specifications, preliminary design reviews, prototyping and testing, and production, with dozens of decisions that require professional judgment at each step, subject to ongoing feedback and revision. Similarly, in both troubleshooting and process improvement work, engineers move through an iterative process to diagnosis problems and test potential solutions or enhancements.

Both the closed-loop and naturalistic approaches to decision-making address DDM, and in doing so illuminate cognitive processes salient to engineering judgment. In the closed-loop model, the situation, decision, and outcome interact in a continuous loop, as shown in Figure 2, with new external information providing ongoing input that informs and changes the decision maker's objectives and/or understanding of the situation.

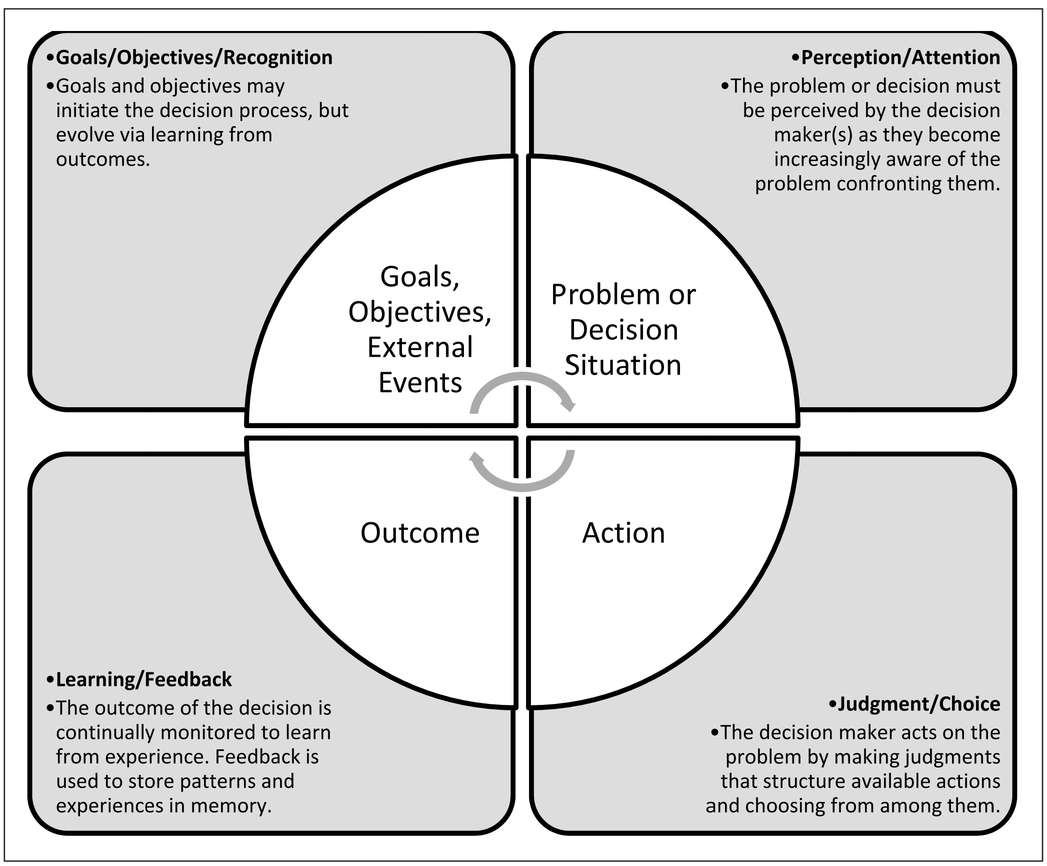

Figure 2 Closed-loop model of decision-making (adapted from Gonzalez 2017).

As Gonzalez explains, in this model, "decisions are influenced by goals and external events and are the result of previous decisions and previous outcomes. Under this view, decision-making is a learning process in which decisions are made based on experiences and are feedback dependent"; she thus refers to decision-making as "a learning loop" (p. 8).

Naturalistic decision-making (NDM) also recognizes the role of learning through experience as a key component of decision-making, and also posit a kind of closed-loop model built on what Klein termed "recognition-primed decision-making" (Klein 2008; Mosier et al. 2018). Recognition-primed decision-making focuses on the ways in which experts compare current situations to past experiences, identify similarities and potential actions or choices, iteratively mentally simulate outcomes of one or more of those choices, and select the first recognizable choice that will produce a viable result (Klein 2008). But where closed-loop studies use experimental approaches (e.g., Instance-Based Learning Theory, IBLT, Gonzalez 2017, p. 11), often with randomized participants in controlled settings, NDM research uses observational or ethnographic approaches to study how experts make decisions in authentic contexts (Gonzalez 2017; Mosier et al. 2018). These contexts often focus on situations that are characterized by large groups of stakeholders, considerable uncertainty about available options, limited available information, and a wide range of costs and consequences, outcomes, or value tradeoffs. Despite these methodological differences, both models also stand in contrast to heuristic-based decision-making, in which individuals rely on commonly accepted rules or short-cuts to make decisions (Gonzalez 2017). Although heuristics are another common feature of engineering and engineering education, research on heuristic-based decision-making includes extensive work on cognitive biases that hinder successful outcomes. Baybutt's (2018) analysis of potential cognitive biases affecting the use of heuristics in hazards analysis is a particularly salient example of the challenges of replacing sound engineering judgment with routine heuristics. Though as Barner et al. (2021) argue, heuristics can be a valuable component of undergraduate education, we exclude them from our current conceptualization because of these limitations.

While significant work remains in decision research, NDM models highlight critical cognitive processes that inform our understanding of both what engineering judgment is and how we might facilitate its development in students. In particular, in addition to routines and the necessary explicit and tacit knowledge in a given domain, the following cognitive processes, summarized by Mosier et al. (2018) are central to experts' exercise of professional judgment in decision-making:

- *Perceptual learning and pattern recognition*, or the ability to recognize the salient features or cues in a given situation and identify similarities to relevant past situations. As Mosier et al. explain, experts "are able to quickly identify the most ecologically valid cues, that is, the subset of information most critical to accurate situation assessment, and to match patterns of cues against patterns in their experience base. Patterns are configurations of cues, including cues that are absent broadly and thus to engineering judgment specifically" (Perceptual Learning and Skills section).
- Construction of *mental models and simulations* that enable experts to understand the underlying structures of a situation, adapt their mental model to critical differences, and use the models to simulate and predict the outcome of different choices.
- *Recognition of typicalities or anomalies*, defined as the ability to identify what elements of a given situation or what results from a given choice are typical and to recognize when either the situation or the outcomes violate expectations. Related to this capacity is the process of *situation assessment, or sense-making*, which relates to experts' ability to comprehend the core of an issue and use action/feedback loops to create updated models of a situation.
- *Metacognition*, or the ability to monitor one's thinking as the situation unfolds and evaluate accuracy and usefulness of one's understanding and choices.
- *Uncertainty management*, or strategies to manage changing conditions, unknown or inconclusive information, time pressure, workload intensity, and related factors (see also the discussion of the challenges inherent in learning from feedback in Gonzalez 2017).

These cognitive processes, of course, depend on domain-specific knowledge, both explicit and tacit, that inform individuals' abilities to understand situations and simulate potential outcomes – the knowledge that typically makes up the bulk of engineering coursework (Lord & Chen 2014). They may also involve knowledge of heuristics as one source of potential actions. Notably, the aspects of cognition noted here are echoed by scholars in engineering education who focus on cognition and note the importance of both underlying mental models and metacognitive awareness (e.g., P. J. Cunningham et al. 2018; Montfort et al. 2009; Streveler et al. 2014) in engineering education broadly. Importantly, however, these processes also move beyond basic domain knowledge and simplified heuristics to reflect the ways experts develop, learn from, and subsequently draw on a repertoire of experiences – what Gonzalez refers to as "context-action exemplars" (Gonzalez 2017, p. 10) (see, for example, recent work by Barner et al. [2021], on the importance of context in the application of engineering heuristics and the differences between academic and workplace applications). Both the closed-loop and naturalistic models emphasize the critical role played by learning from experience – by encountering an open-ended situation, exercising judgment to identify and implement initial decisions, and observing and learning from the outcomes of those decisions to inform future judgments. Across the research in this field, the findings suggest that as situations increase in complexity, individuals are more and more likely to make decisions based on experience (Gonzalez 2017; Klein 2008; Mosier et al. 2018).

DECISION-MAKING IN TEAMS

While cognitive science research has historically focused on decision-making by individuals (Gonzalez 2017; Mosier et al. 2018), in practice, especially in engineering, decisions typically emerge in and through collaborative contexts (Trevelyan 2010, 2014a; Weedon 2019). Increasingly, particularly in naturalistic decision-making research, scholars have been exploring team cognition (Mosier et al. 2018). Research in this space has highlighted the importance of shared mental models among team members as well as the centrality of communication. As Mosier et al. (2018) note in summarizing this research, "Expert teams also tend to discuss the problem they face and the responses to it in great detail. Team members let others in on their reasoning and inform them about their expectations. They ensure common ground by providing feedback and mitigate errors through team-centered communication" (Expert Teams section). Such findings suggest that in addition to the cognitive processes needed to develop professional judgment in a given context, individuals also need discursive process that enable them to articulate and negotiate judgments in collaborative contexts. Recent work by Wilde and Guile (2021) in science and technology studies (STS) echoes the centrality of discursive negotiations in a study of engineers' situated judgment in cross-functional client-focused project teams. Their work illuminates the ways in which, as teams enact situated judgment, "ideas arise and are tested out discursively [in ways that] may require teams to go beyond engineering standards and usual ways of working" (p. 188) to construct or improvise new alternatives. Work in other professional fields yields similar findings. For example, work by Cristancho et al. (2017) in medical decision-making illuminates the ways judgment emerges from the improvisational interactions of individuals and artifacts in the surgical theater to produce new understandings of a situation and corresponding new decisions. Such research demonstrates that professional judgment is not an isolated act but is something that emerges as both individuals and teams of professionals continuously engage in their work as it evolves in context. Furthermore, within engineering teams, Weedon's (2019) work illustrates the ways these improvisations are mediated through rhetorical practices that enable team members to use embodied knowledge to facilitate shared understanding of a decision situation. Thus both the cognitive science research on team decision-making and the emerging rhetorical research on decision-making and judgment clear space for expanding our understanding of judgment to include discourse, and, we argue in the next section, particularly discursive identity.

4. RHETORICAL CONCEPTIONS OF JUDGMENT AND THE CONSTRUCTION OF DISCURSIVE IDENTITIES

As the preceding section demonstrates, both cognitive science research on decision-making and STS research on engineering work reflect the role of discourse in the exercise of judgment. Parallel work in writing studies, including emerging work by Weedon (2016; 2017; 2019) as well as recent findings from our own studies (Francis et al. 2021; Francis et al. 2021, 2022) have begun to identify the rhetorical underpinnings of engineering judgment in ways that suggest in addition to being a cognitive act, engineering judgment is also a discursive one. We carry this framework one step further, however, and draw on James Gee's concept of discourse identity to suggest that part of making and negotiating engineering judgments is the process of being recognized – by oneself and others – as someone who *can* make engineering judgments. The links between engineering judgment and identity broadly are embedded in Davis' (2012) philosophical plea in that he notes multiple ways in which judgment is personal in that it reflects a disposition or willingness to act rather than simply the ability to do so. We argue further that this disposition is also inherently undergirded by the perception of oneself as someone who can act, who can render judgments on ill-defined, ambiguous, open-ended issues. This attention to discourse identity aligns closely with research on engineering practice by Trevelyan (2010, 2014b), Bucciarelli (2001), Wilde and Guile (2021) and others, that foregrounds the social nature of engineering work, in which communication plays a central role and the disposition to render judgments also always involves the recognition – by oneself and others – of the capacity to express, defend, and negotiate those judgments.

4.1 IDENTITY AND DISCOURSE

To ground this conceptualization of engineering judgment as an act of discursive identity, we first draw on James Gee's work (2000). In considering identity as an analytic lens, Gee posits that "when any human being acts and interacts in a given context, others recognize that person as acting and interacting as a certain 'kind of person'" (p. 99). He thus frames identity as "being recognized as a certain kind of person" (p. 99). He then offers four different approaches to this recognition, one of which is discursive identity – the identity that emerges in "the discourse or dialogue of other people" (p. 103). That is, an individual's identity is constructed in how others talk with and about them, as well as how the individual constructs themselves in and through these dialogic interactions. Paretti and McNair (2012), for example, adopt this framework to examine the ways in the discursive interactions within interdisciplinary project teams constrain and enable the identities available to engineers in different settings. The ways people talk with and about the engineers on the team, as well as how the engineers talk about themselves, serve to position them alternately as bottlenecks or collaborative designers and shapes their contributions to the project at hand.

Gee's concept of discursive identity is closely linked to the rhetorical construct of ethos: that which lends credibility to an engineer's judgments in their own eyes as well as in the eyes of others (e.g., House et al. 2014). One source of this credibility is the perceived ability to apply specialized knowledge and analytic techniques – appealing to objective facts, physical data, or mathematical theory – to interpret information in ways that lead to meaningful judgments and sound application. This application of specialized knowledge echo's McLaughlin's (2021) definition of engineering judgment cited earlier, which emphasizes the application of "mathematically and scientifically derived principles" (p. 216). The perceived ability to dispassionately and objectively apply specialized knowledge functions as one source of the engineering ethos that undergirds judgment; cognitive research, as noted earlier, highlights specialized domain knowledge a key component of professional judgment (Mosier et al. 2018). But as the preceding section makes clear, in practice engineering judgment is not simply an objective application of irrefutable mathematical and physical facts to reach a single unambiguous answer. Instead, it encompasses a cognitively complex, experience-based interpretation of an ambiguous situation that, in engineering contexts, often involves social, economic, cultural, and political dimensions as well as technical ones. The ability to, as Gee says, "be recognized as" someone capable of rendering professional judgments is crucial when data are sparse or ambiguous, problems are poorly formed, and decisions are made more challenging in the face of complexity and low-probability high-consequence events with little historical data – scenarios that dominate professional engineering work (Jonassen 2014; Trevelyan 2010; Trevelyan & Williams 2018; Williams & Figueiredo 2014).

Case studies of engineering practice bear out the centrality of discourse in constructing and validating the credibility of engineering judgments and the identities of engineers as credible judges. For example, in investigating engineering ethos, House et al. (2014) present a rhetorical analysis of a Congressional hearing on coal ash waste in which the judgment of the engineers involved was contested through attempts to separate the seemingly objective technical dimensions from the inextricable social and policy dimensions that complicated potential decisions. In part, this study highlights the inextricable interaction of technical and social factors of engineering judgment and the ways in which "technical expertise is not necessarily disinterested [but instead] complicated interests and even incommensurable goals and values are unavoidable" (p. 6). Equally important, however, their analysis of the testimony and subsequent interrogation illuminates the ways in which being recognized as an expert capable of rendering engineering judgments is contested in and through discourse. In this case, an elected representative from a coal district repeatedly questioned the judgments of the engineer testifying before the hearing. Early accounts analyzing the decision to launch the space shuttle *Challenger* against the judgments of the engineers highlight similar discursive complexities surrounding both how engineers make and position their judgments and how others engage with, accept, or reject those judgments (Dombrowski 1992; Herndl et al. 1991; Lynch & Kline 2000; Winsor 1988, 1990). And as Ternes (2019) notes, debates over 'good engineering judgment' can play out in civil litigation over damage resulting from industrial accidents – particularly as increases in extreme weather events increase the damage risk.

Across these cases, the validity of engineers' judgments is always linked to their discursive identities. That is, these and related studies highlight the ways in which engineers must not only demonstrate their capacity to enact the cognitive processes that comprise engineering judgment but must also discursively construct identities that reinforce this capacity. These identities enable students to position themselves as capable of rendering and communicating meaningful engineering judgments in ways that are rhetorically and discursively credible. Importantly, as Weedon (2019) points out, echoing the findings from cognitive science on team processes (Mosier et al. 2018), this communicative work is not simply something that happens *after* a judgment is reached, but is integral to the process of exercising judgment since judgments are the result not only of individual actions but also emerge from the ways engineering judgments are constructed from the perceptions and interactions among individuals working together on teams.

4.2 IDENTITY AS CULTURAL PRODUCTION

As Gee (2000) notes, however, discursive constructions of identity are also always embedded in what he refers to as Discourse with a capital D – the socially and historically constructed community or cultural narratives that to a large extent shape the identities (discourse or otherwise) that are available to individuals and that individuals refer to and negotiate with. Within engineering education, Karen Tonso's work (2006a, 2006b) on the cultural production of engineering identities offers a useful lens for framing the ways in which identity is always constructed within and against larger cultural narratives. Cultural production theory examines the ways in which individual identities are constructed through ongoing informal interactions in the context of a larger set of existing beliefs, values, and practices (what Holland et al. [1998] term *figured worlds*). Drawing on the work of Holland et al., Willis (1977), and others, Tonso (2006a, 2006b) used cultural production theory to explore the ways student engineers present themselves and are recognized by others as engineers through participation in campus communities and team projects. Focusing on the social and institutional features that constitute the context within which students enact their engineering identities, Tonso describes engineering identity production as "a complicated process that [binds] up thinking about oneself as an engineer, performing an engineer self, and ultimately being thought of as an engineer" (2006a, pp. 273–274). Her work shifts the focus from engineering identity as a characteristic or feature held by an individual and toward the ways that the social and institutional features, and in particular, language, create cultural spaces that yield particular expectations and pressures that affect the types of identities the students perform. She looked, for example, at the various terms available to describe engineers within one particular institution (e.g., *geek, hacker, curve-breaker, slacker*) and explored the ways in which those terms and the associated identities constrained or enabled individual engineering students to act in various settings. Existing cultural forms thus define sets of norms and expectations that individuals engage with as they negotiate and construct their identities. And such cultural production is not limited to students; recent work by Gewirtz (Gewirtz 2021, Gewirtz et al. 2021) draws on Holland et al. as well to examine the ways in which new engineers construct their professional identities within and against those made available by the norms, values, and structures of their organizations.

In the context of engineering judgment, we argue that cultural production theory offers a means to understand the context in which discursive identities, including those related to exercising professional judgment, are negotiated and enacted. That is, discursive identities are not constructed through decontextualized conversations among individuals; rather, they are situated within larger cultural forms circumscribing what it means to be both an engineering student and an engineer. Tonso's accounts of the ways in which students interacted on engineering design teams highlight the ways in which individuals' credibility – in short, the legitimacy of their judgments about project decisions – were shaped by cultural norms continuously reenforced by both peers and faculty. Importantly, those norms, particularly for students who did not conform to them, also served to inhibit individuals' ability to construct validated engineering identities (Tonso 2006a, 2007) and, we would add, exercise engineering judgments that others perceived as legitimate and valued.

Cultural production theory suggests, then, that exercising engineering judgment in a way that is recognizable to others requires individuals to construct identities that draw on the socially and culturally meaningful practices – those practices recognized as "good engineering" broadly. And as the work on discursive identity, as well as the research by Tonso and others, suggests, language plays a critical role in the process of cultural production. Engineers must be able to construct their judgments in and through discourse in ways that are recognizable as credible, meaningful, actionable, and valid.

5. LEARNING ENGINEERING JUDGMENT

As we have suggested in the preceding sections, developing and exercising engineering judgment requires a complex interplay of cognitive and discursive processes within the context of engineering work. Figure 1 illustrates this interplay to define engineering judgment as a holistic participatory capacity situated within the complex, open-ended, socio-technical contexts of engineering work that integrates the cognitive processes underpinning naturalistic decision-making with the cultural and discursive production of professional identities needed to effectively negotiate judgments. Engineering judgment is fundamentally situated in a context characterized by complexity, ambiguity, uncertainty, potentially conflicting goals, sometimes divergent stakeholders, highly collaborative work, and recognized professional practices. Facets of engineering work such as uncertainty and ambiguity, as in many professions, mean that enacting judgment requires engineers to engage in a series of cognitive processes that include recognizing salient features and key patterns within a given situation, relying on mental models and simulations to predict potential outcomes of various alternatives, metacognitively monitoring the outcomes of choices, and using both feedback and new input to learn and revise judgments. At the same time, the collaborative nature of engineering work both requires and enables engineers to engage in these cognitive processes in dynamic negotiation with others. To do so, they must simultaneously construct individual and collective identities in and through language that empower them to negotiate judgments; this process, however, is always framed by the identities that are culturally available in a given context. Engineers embody and negotiate these identities as they interact with other professionals to enact the cognitive practices that comprise naturalistic decision-making. Viewed in this holistic way, engineering judgment is a capacity that professionals develop as they assume multiple roles, experience multiple personal and professional contexts, and come to recognize a range of patterns and social practices as they accumulate decision-making experience over the course of their career trajectories.

As noted at the outset, our goal in building this framework is to help establish a more concrete understanding of engineering judgment that can inform the design of both educational experiences and future research. Toward that end, we offer suggestions for both educators and researchers for how this framework might inform future practice.

IMPLICATIONS FOR EDUCATION

With respect to educators, this conceptualization of engineering judgment highlights several domains for engineering learning. To support the cognitive components, educational experiences should help emerging engineers develop the capacities to interpret ill-structured or ambiguous situations in ways that allow them to collaboratively or independently, to i) identify potential pattern matches; ii) distinguish typical versus anomalous situations; iii) apply appropriate mental models that allow them to simulate outcomes of choices; iv) monitor their own and their group's thinking and the evolving situation; and, v) manage uncertainty and ambiguity. To that end, current research identifying effective practices for helping students build mental models (e.g., Johnson-Glauch et al. 2020; Streveler et al. 2014; Yang et al. 2020), develop expertise (e.g., Litzinger et al. 2011; McKenna 2014), and engage in metacognition (P. J. Cunningham et al. 2018; Magana et al. 2019) can and should directly inform educators in designing relevant experiences.

The decision-making component of our framework, together with the context of engineering work, also aligns with established arguments for the centrality of authentic open-ended project work in engineering education (Johri et al. 2014; Jonassen 2014; Stevens et al. 2014). Skill-and-drill problem sets characteristic of many technical engineering courses (Lord & Chen 2014) are not sufficient, nor is a single design experience in the senior year – or even "bookended" cornerstone and capstone experiences. Closed-loop decision-making, as indicated in Section 3, involves the evolution of situational awareness, objectives, and preferences for outcomes based on closing the feedback loop from observing the outcomes of decisions and adjusting decision processes accordingly. Educators can help students engage in this process, then, by providing repeated opportunities for exercising judgment and learning from experience, through targeted feedback from experts, opportunities to fail, and, critically, prompts to reflect on and learn from both failures and successes in ways that mirror the practices of expert capstone design educators (Pembridge & Paretti 2019). These practices may also support metacognitive development as well as tolerance for uncertainty and ambiguity (see, for example, work on self-directed learning in capstone courses by M. Paretti et al. [2020], though significant work remains in this area). Faculty need to design assignments and project schedules in ways that facilitate such learning; notably, such facilitation typically includes the need for educators to directly observe student processes and interactions through a range of developmental points within a complex assignment or activity.

At the same time, as the identity component of our framework indicates, to enact the cognitive capacities involved in negotiating judgments, emerging engineers must be recognized by others (faculty and peers) and recognize themselves as individuals capable of exercising judgments – a recognition that happens through language. For educators, this recognition involves attending carefully both to how we talk to our students and how we teach them to talk to each other. The importance of classroom language is evident, for example, in work on student agency in capstone settings by Svihla et al. (2021). They draw on the concept of *opportunity structure*, defined as "the possible and perceived decision space that is shaped by a range of factors, including prior experiences and norms, cultures, and policies." Though they do not address judgment directly, their study focuses on the contextual and discursive factors that shape the extent to which capstone teams perceive and act on the freedom to make decisions regarding the scope of their projects. The findings highlight the essential role played by both teaching assistants and student leaders on in each team in creating the space to make decisions – and consequently, we suggest, to exercise the judgments that precedes it. Specifically, the ways in which TAs and team leaders talked about the projects could either invite or close down alternatives; in doing so, we suggest, they also made certain identities available to students or foreclosed them. External clients, as well as students' perceptions and beliefs about course projects and expectations, also heavily influenced the extent to which team members perceived their own agency in making project choices. The findings from Svihla et al. demonstrate the ways these larger curricular structures discursively constructed the identities students considered available to them, while the local team interactions reflected the ways in which students did or did not recognize one another (and themselves) as capable of and invited to make judgments. These findings thus highlight the ways in which educators need to talk with students in ways that support such recognition.

The influence of classroom and interpersonal discourse also points to the need for educators to design writing and speaking assignments that invite students to build discursive identities directly aligned with exercising engineering judgment. Allie et al. (2009) set forth a compelling case for learning as discursive identity acquisition over a decade ago, drawing on Gee as well as Lea and Street (2006) and others to highlight the importance of helping students recognize and become fluent in the language of their disciplines. Relative to engineering judgment specifically, educators need to provide students with multiple opportunities to justify and negotiate decisions in the context of engineering work, both in writing and verbally, formally and informally. As Wilde and Guile (2021) explain,

> (i) human interactions rely on different forms of justification; (ii) there are always different conceptions of worth or value playing out in any situation; and, (iii) therefore it is inevitable that different types of justifications, ultimately, have to be reconciled with one another. (p. 188)

They go on to note that "the discussions and deliberations create a shared understanding of how the different conceptions of value may play a part in resolving an issue that the team is currently concerned with" (p. 189). We posit, in turn, that it is through these discussions and deliberations that students both develop their facility with disciplinary discourse and enact discursive identities as emerging professionals who are recognized, and recognize themselves, as capable of making engineering judgments.

Developing these capacities require faculty to design writing assignments and project assignments that foreground both students' ability to justify their decisions and their capacities to negotiate, test, and revise those decisions with each other. Work by Paretti (2006), for example, offers one starting point in shifting writing assignments from knowledge performance to engaged practice, and thus moving the instructor from evaluator to responder in ways that make space for students to construct professional identities. And work on peer review in engineering writing suggests opportunities for students to engage with each other around how texts are constructed and revised (e.g., Ekoniak 2018). Notably, however, as early work by Berkenkotter (1984) suggests, most students are not used to negotiating texts with one another or with instructors. Writing for responsive readers requires students to contest claims of authority and reflect on the needs of their audience in ways that might be abrogated through normal cycles of professor feedback. Berkenkotter (1984) found that students responded quite differently to feedback based on the writer's personality, maturity, and nature of the feedback. In other words, the authors implicitly (sometimes explicitly) assumed a certain degree of authority over their texts and assessed the validity of the feedback against the degree of authority they were willing to yield to their peer audience behind the feedback. Within engineering, the larger school culture of right and wrong answers, as well as the focus within engineering on just getting projects finished (Svihla et al. 2021; Goncher & Johri 2015) makes it challenging for educators to facilitate negotiated judgments. Recommendations such as those by Goncher and Johri, Svihla et al., Paretti, and others can help, as can the kinds of discursive practices identified by Hmelo-Silver et al. (2008) for problem-based learning facilitators.

As the preceding discussion suggests, engineering judgment cannot be built through a single educational experience. Rather, the framework we propose suggests that across a curriculum, students need to build conceptual frameworks and mental models that support prediction in uncertain or ambiguous contexts, accumulate a series of open-ended project experiences that begin to develop a repertoire of potential typical and anomalous patterns, develop metacognitive skills that allow them to monitor and learn from feedback and failure, and negotiate and justify decisions both orally and in writing in ways that position them as capable of and responsible for exercising engineering judgment. Still, more work remains to identify both how to design and how to implement assignments that facilitate the development of engineering judgment. Critical issues such as how to meaningfully integrate opportunities for judgment developmentally across a curriculum; how to balance the perceived need to cover course content with the need to introduce experiences of ambiguity, uncertainty, and autonomy; and how to assess both the individual cognitive and discursive practices and the cumulative, collaborative enactment of engineering judgment remain practical problems.

IMPLICATIONS FOR RESEARCHERS

The framework we proposed also offers multiple avenues for future research. In the domain of decision-making, for example, it offers the opportunity to link existing work on cognition to the specific cognitive processes associated with judgment and to examine the ways in which students do or do not apply processes such as mental models or metacognition to situations requiring judgment. It also affords the opportunity to continue to explore how students learn to respond to ambiguity and uncertainty, particularly within a domain that often emphasizes the idea of a "right" answer, and how their responses to uncertainty influence their enactment of judgment. Similarly, in the domain of discursive identity, it offers the opportunity to explore the ways in which both writing assignments and team dynamics do or do not make available to students the identity needed to enact engineering judgment. How, that is, do writing assignments, instructor-student, and student-student interactions help students recognize themselves and one another as people capable of negotiating judgments together? At the same time, given the broader research on engineering identity, scholars might also explore how do students' conceptualizations of engineering identity do or do not include the capacity for engineering judgment.

However, in positioning engineering judgment at the intersection of the cognitive processes of decision-making and the cultural production of discursive identity within the context of engineering work, we also necessarily excluded other potentially relevant domains that could inform future expansions of this model. As our discussion of the relevant background theories suggests, our proposed framework is also linked to other areas of research within engineering education, including the work on expertise and engineering ethics noted earlier, as well as other areas such as critical thinking, computational thinking, design thinking, or science agency. For example, we need to understand much more about how both expert and student engineers exercise engineering judgment, similar to earlier work by Atman et al. (2007) illuminating salient differences in expert and student design processes, and how these differences might align with the broader literature on expertise.

Finally, while beyond the scope of this article, the focus on identity in this framework, also has potential implications for diversity, equity, and inclusion in engineering. As many scholars have argued, the marginalization and exclusion of students who do not fit the normative stereotype of engineering (i.e., White, male, cis-gendered, heterosexual) reflects prominent facets of engineering culture that continuously reproduce and validate some identities over others. For example, Tonso's work highlights the ways in which the cultural production of engineering identity often excludes women, and work by Riley et al. (Riley 2008; Riley et al. 2014), McCall et al. (2020), Cech and Waidzunas (2011), McGee and Martin (2011), and others have similarly highlighted cultural exclusions along race, (dis)ability, and sexual orientation. Their work, in conjunction with our proposed framework, suggests that these cultural exclusions may also limit who is recognized as able to enact engineering judgment. Since, as we have argued, students must be recognized as capable of making engineering judgments, our theory of engineering judgment presents a site for explicit discussion of the social and power dynamics that can influence the construction of engineering work by limiting or amplifying the participation of individual students in engineering judgment acts based on perception of identity.

To that end, more work needs to be done to understand how students discursively position themselves and others within design projects, how they conceptualize their own and their peers' engineering identities relative to engineering judgment, and how their written and oral discourse practices support or hinder the development of this core professional capacity. Such work can build on the strong research base in engineering identity that has emerged in recent years in engineering education (e.g., Godwin et al. 2016, Ross et al. 2021, Gewirtz and Paretti 2021) that continues to point towards the centrality of identity construction in supporting the personal and professional development of engineering students. Engineering judgment, as a capacity and an identity, has a critical role to play in that space.

ACKNOWLEDGEMENTS

This research is supported by the National Science Foundation (NSF) under Grant Numbers 1927035 and 1927096. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

COMPETING INTERESTS

Marie C. Paretti is a founding Co-Editor-In-Chief of *Studies in Engineering Education*. She is also on the editorial advisory board for the *Journal of Business and Technical Communication*. RF and RR have no competing interests.

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REFERENCES

ABET Engineering Accreditation Commission. (2018). *2019–2020 Criteria for Accrediting Engineering Programs*. A. E. A. Commission. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/

Allie, S., Armien, M. N., Burgoyne, N., Case, J. M., Collier-Reed, B. I., Craig, T. S., Deacon, A., Fraser, D. M., Geyer, Z., Jacobs, C., Jawitz, J., Kloot, B., Kotta, L., Langdon, G., le Roux, K., Marshall, D., Mogashana, D., Shaw, C., Sheridan, G., & **Wolmarans, N.** (2009). Learning as acquiring a discursive identity through participation in a community: improving student learning in engineering education. *European Journal of Engineering Education*, *34*(4), 359–367. DOI: https://doi.org/10.1080/03043790902989457

Atman, C. J., Adams, R. S., Cardella, M. E., Turns, J., Mosberg, S., & **Saleem, J.** (2007, October). Engineering design processes: A comparison of students and expert practitioners. *Journal of Engineering Education*, *96*(4), 359–379. DOI: https://doi.org/10.1002/j.2168-9830.2007.tb00945.x

Barner, M. S., Brown, S. A., & **Linton, D.** (2021). Structural engineering heuristics in an engineering workplace and academic environments. *Journal of Civil Engineering Education*, *147*(2), 04020014. DOI: https://doi.org/10.1061/(ASCE)EI.2643-9115.0000029

Baybutt, P. (2018). The validity of engineering judgment and expert opinion in hazard and risk analysis: The influence of cognitive biases. *Process Safety Progress*, *37*(2), 205–210. DOI: https://doi.org/10.1002/prs.11906

Berkenkotter, C. (1984). Student writers and their sense of authority over texts. *College Composition and Communication*, *35*(3), 312–319. http://www.jstor.org/stable/40171130. DOI: https://doi.org/10.2307/357459

Bornasal, F., Brown, S., Perova-Mello, N., & **Beddoes, K.** (2018). Conceptual growth in engineering practice. *Journal of Engineering Education*, *107*(2), 318–348. DOI: https://doi.org/10.1002/jee.20196

Bruhl, J. C., Klosky, J. L., Mainwaring, T., & **Hanus, J. P.** (2017). Accelerating the development of engineering judgment in students through inquiry-based learning activities. *2017 ASEE Annual Conference & Exposition*. http://peer.asee.org/27532. DOI: https://doi.org/10.18260/1-2--27532

Bucciarelli, L. L. (2001). Design knowing and learning: A socially mediated activity. In W. C. Newstetter, C. Eastman & M. McCraken (Eds.), *Design Knowing and Learning: Cognition in Design Education* (pp. 297–313). Elsevier Science Ltd. DOI: https://doi.org/10.1016/B978-008043868-9/50013-9

Cech, E. A., & **Waidzunas, T. J.** (2011). Navigating the heteronormativity of engineering: The experiences of lesbian, gay, and bisexual students. *Engineering Studies*, *3*(1), 1–24. DOI: https://doi.org/10.1080/19378629.2010.545065

Civil Engineering Body of Knowledge 3 Task Committee. (2019). *Civil Engineering Body of Knowledge: Preparing the Future Civil Engineer* (3rd ed.). American Society of Civil Engineers. DOI: https://doi.org/10.1061/9780784415221

Cristancho, S., Lingard, L., Forbes, T., Ott, M., & **Novick, R.** (2017). Putting the puzzle together: The role of 'problem definition' in complex clinical judgement. *Medical Education*, *51*(2), 207–214. DOI: https://doi.org/10.1111/medu.13210

Cunningham, P., Matusovich, H. M., Hunter, D.-A., Williams, S. A., & **Bhaduri, M. S.** (2017). Beginning to understand student indicators of metacognition. *2017 ASEE Annual Conference and Exposition*. https://peer.asee.org/27820. DOI: https://doi.org/10.18260/1-2--27820

Cunningham, P. J., Matusovich, H. M., Venters, C., Williams, S. A., & **Bhaduri, S.** (2018). The impact of metacognitive instruction on students' conceptions of learning and their self-monitoring behaviors. *2018 ASEE Annual Conference and Exposition*. https://peer.asee.org/29999. DOI: https://doi.org/10.18260/1-2--29999

Davis, D. C., Beyerlein, S. W., & **Davis, I. T.** (2005). Development and use of an engineer profile. *2005 ASEE Annual Conference and Exposition,* Portland, OR. https://peer.asee.org/14201. DOI: https://doi.org/10.18260/1-2--14201

Davis, M. (2012). A plea for judgment. *Science and Engineering Ethics*, *18*(4), 789–808. DOI: https://doi.org/10.1007/s11948-011-9254-6

Dombrowski, P. (1992). *Challenger* and the social contingency of meaning: Two lessons for the technical communication classroom. *Technical Communication Quarterly*, *1*(1), 73–85. DOI: https://doi.org/10.1080/10572259209359507

Ekoniak, M. R. (2018). *Practice and efficacy of peer writing feedback in a large first-year engineering course*. [Doctoral Dissertation, Virginia Tech]. Blacksburg, VA. http://hdl.handle.net/10919/95551. DOI: https://doi.org/10.1109/FIE.2018.8659050

Ford, J., Paretti, M., Kotys-Schwartz, D., Howe, S., & **Ott, R.** (2021). New Engineers' Transfer of Communication Activities From School to Work. *IEEE Transactions on Professional Communication*, *64*(2), 105–120. DOI: https://doi.org/10.1109/TPC.2021.3065854

Francis, R., Riedner, R., & **Paretti, M. C.** (2021). A thematic analysis of the intersection of engineering judgment and student writing practices. *2021 Research in Engineering Education Symposium*. https://aaee.net.au/wp-content/uploads/2021/11/REES_AAEE_2021_paper_303.pdf

Francis, R. A., Paretti, M. C., & **Riedner, R.** (2022). The WRI²TES Project: Writing Research Initiating Identity Transformation in Engineering Students. *2022 ASEE Annual Conference and Exposition*. https://strategy.asee.org/42002

Francis, R. A., Riedner, R. C., & **Paretti, M. C.** (2021). A dramaturgical exploration of engineering judgment processes in undergraduate student writing. *2021 IEEE Frontiers in Education Conference*. DOI: https://doi.org/10.1109/FIE49875.2021.9637349

Gainsburg, J. (2006). The mathematical modeling of structural engineers. *Mathematical Thinking and Learning*, *8*(1), 3–36. DOI: https://doi.org/10.1207/s15327833mtl0801_2

Gainsburg, J. (2013). Learning to model in engineering. *Mathematical Thinking and Learning*, *15*(4), 259–290. DOI: https://doi.org/10.1080/10986065.2013.830947

Gainsburg, J., & **Gainsburg, J.** (2007). The mathematical disposition of structural engineers. *Journal for Research in Mathematics Education*, *38*(5), 477–506. https://www.jstor.org/stable/30034962

Gee, J. P. (2000). Identity as an analytic lens for research in education. *Review of Research in Education*, *25*(1), 99–125. DOI: https://doi.org/10.2307/1167322

Gewirtz, C. (2021). *Twelve Tales of Engineering in the "Real World:" Narratives of Newcomers' Agency in Transitions to Engineering Work* [Doctoral Dissertation, Virginia Tech]. Blacksburg, VA. http://hdl.handle.net/10919/104897

Gewirtz, C., & **Paretti, M. C.** (2021). Becoming after College: Agency and Structure in Transitions to Engineering Work. *Engineering Studies*, 13(2), 111–131. DOI: https://doi.org/10.1080/19378629.2021.1959597

Godwin, A., Potvin, G., Hazari, Z., & **Lock, R.** (2016). Identity, critical agency, and engineering: An affective model for predicting engineering as a career choice. *Journal of Engineering Education*, *105*(2), 312–340. DOI: https://doi.org/10.1002/jee.20118

Goncher, A., & **Johri, A.** (2015). Contextual constraining of student design practices. *Journal of Engineering Education*, *104,* 252–278. DOI: https://doi.org/10.1002/jee.20079

Gonzalez, C. (2017). Decision-making: A cognitive science perspective. In E. F. C. Susan (Ed.), *The Oxford Handbook of Cognitive Science*. Oxford University Press. DOI: https://doi.org/10.1093/oxfordhb/9780199842193.013.6

Herndl, C. G., Fennell, B., & **Miller, C.** (1991). Understanding failures in organizational discourse: The accident at three mile island and the shuttle *Challenger* disaster. In C. Bazerman & J. Paradis (Eds.), *Textual Dynamics of the Professions* (pp. 279–305). University of Wisconsin Press.

Hmelo-Silver, C. E., & **Barrows, H.** (2008). Facilitating collaborative knowledge building. *Cognition and Instruction*, *26*(1), 48–94. DOI: https://doi.org/10.1080/07370000701798495

Holland, D., Lachicotte, W. J., Skinner, D., & **Cain, C.** (1998). *Identity and agency in cultural worlds*. Harvard University Press.

House, R. A., Layton, R., Livingston, J., & **Moseley, S.** (2014). Engineering ethos in environmental public policy deliberation. *2014 IEEE International Professional Communication Conference*. DOI: https://doi.org/10.1109/IPCC.2014.7020384

Jesiek, B. K., Buswell, N. T., & **Nittala, S.** (2021). Performing at the boundaries: Narratives of early career engineering practice. *Engineering Studies*, *13*(2), 86–110. DOI: https://doi.org/10.1080/19378629.2021.1959596

Jesiek, B. K., Woo, S. E., Parrigon, S., & **Porter, C. M.** (2020). Development of a situational judgment test for global engineering competency. *Journal of Engineering Education*, *109*(3), 470–490. DOI: https://doi.org/10.1002/jee.20325

Johnson-Glauch, N., Choi, D. S., & **Herman, G.** (2020). How engineering students use domain knowledge when problem-solving using different visual representations. *Journal of Engineering Education*, *109*(3), 443–469. DOI: https://doi.org/10.1002/jee.20348

Johri, A., Olds, B. M., & **O'Connor, K.** (2014). Situative frameworks for engineering learning research. In A. Johri & B. M. Olds (Eds.), *Cambridge Handbook of Engineering Education Research* (pp. 47–66). Cambridge University Press. DOI: https://doi.org/10.1017/CBO9781139013451.006

Jonassen, D., Strobel, J., & **Lee, C. B.** (2006). Everyday problem solving in engineering: Lessons for engineering educators. *Journal of Engineering Education*, *95*(2), 139–151. DOI: https://doi.org/10.1002/j.2168-9830.2006.tb00885.x

Jonassen, D. H. (2014). Engineers as problem solvers. In A. Johri & B. M. Olds (Eds.), *Cambridge Handbook of Engineering Education Research*. Cambridge University Press. DOI: https://doi.org/10.1017/CBO9781139013451.009

Kahneman, D., & **Tversky, A.** (1979). Prospect theory: An analysis of decision under risk. *Econometrica*, *47*(2), 263–292. http://www.jstor.org/stable/1914185. DOI: https://doi.org/10.2307/1914185

Klein, G. (2008). Naturalistic decision-making. *Human Factors*, *50*(3), 456–460. DOI: https://doi.org/10.1518/001872008X288385

Lea, M. R., & **Street, B. V.** (2006). The "academic literacies" model: Theory and applications. *Theory into Practice*, *45*(4), 368–377. DOI: https://doi.org/10.1207/s15430421tip4504_11

Litzinger, T. A., Lattuca, L. R., Hadgraft, R. G., Newstetter, W. C., Alley, M., Atman, C., DiBiasio, D., Finelli, C., Diefes-Dux, H., Kolmos, A., Riley, D., Sheppard, S., Weimer, M., & **Yasuhara, K.** (2011). Engineering education and the development of expertise. *Journal of Engineering Education*, *100*(1), 123–150. DOI: https://doi.org/10.1002/j.2168-9830.2011.tb00006.x

Lord, S. M., & **Chen, J. C.** (2014). Curriculum Design in the Middle Years. In A. Johri & B. M. Olds (Eds.), *Cambridge Handbook of Engineering Education Research* (pp. 181–200). Cambridge University Press. DOI: https://doi.org/10.1017/CBO9781139013451.014

Lynch, W. T., & **Kline, R.** (2000). Engineering practice and engineering ethics. *Science, Technology, & Human Values*, *25*(2), 195–225. DOI: https://doi.org/10.1177/016224390002500203

MacRobert, C. J. (2018). Introducing engineering judgment through active learning. *Journal of Professional Issues in Engineering Education and Practice*, *144*(4), 05018009-05018001-05018009-05018010. DOI: https://doi.org/10.1061/(ASCE)EI.1943-5541.0000382

Magana, A. J., Fennell, H. W., Vieira, C., & **Falk, M. L.** (2019). Characterizing the interplay of cognitive and metacognitive knowledge in computational modeling and simulation practices. *Journal of Engineering Education*, *108*(2), 276–303. DOI: https://doi.org/10.1002/jee.20264

McCall, C., Shew, A., Simmons, D. R., Paretti, M. C., & **McNair, L. D.** (2020). Exploring student disability and professional identity: navigating sociocultural expectations in U.S. undergraduate civil engineering programs. *Australasian Journal of Engineering Education*, *25*(1), 79–89. DOI: https://doi.org/10.1080/22054952.2020.1720434

McCord, R. E., & **Matusovich, H. M.** (2019). Naturalistic observations of metacognition in engineering: Using observational methods to study metacognitive engagement in engineering. *Journal of Engineering Education*, *108*(4), 481–502. DOI: https://doi.org/10.1002/jee.20291

McGee, E. O., & **Martin, D. B.** (2011). 'You would not believe what I have to go through to prove my intellectual value!' Stereotype management among academically successful black mathematics and engineering students. *American Educational Research Journal*, *48*(6), 1347–1389. DOI: https://doi.org/10.3102/0002831211423972

McKenna, A. F. (2014). Chapter 12 – Adaptive expertise and knowledge fluency in design and innovation. In A. Johri & B. M. Olds (Eds.), *Cambridge Handbook of Engineering Education Research* (pp. 227–242). Cambridge University Press. DOI: https://doi.org/10.1017/CBO9781139013451.016

McLaughlin, D. (2021). Engineering, judgment and engineering judgment: A proposed definition. In Z. Pirtle, D. Tomblin & G. Madhavan (Eds.), *Engineering and Philosophy: Reimagining Technology and Social Progress* (pp. 199–217). Springer International Publishing. DOI: https://doi.org/10.1007/978-3-030-70099-7_10

Montfort, D., Brown, S., & **Pollock, D.** (2009). An investigation of students' conceptual understanding in related sophomore to graduate-level engineering and mechanics courses. *Journal of Engineering Education*, *98*(2), 111–129. DOI: https://doi.org/10.1002/j.2168-9830.2009.tb01011.x

Mosier, K., Fischer, U., Hoffman, R. R., & **Klein, G.** (2018). Expert professional judgments and "naturalistic decision-making". In A. M. Williams, A. Kozbelt, K. A. Ericsson & R. R. Hoffman (Eds.), *The Cambridge Handbook of Expertise and Expert Performance* (2 ed., pp. 453–475). Cambridge University Press. DOI: https://doi.org/10.1017/9781316480748.025

National Academy of Engineering. (2004). *The Engineer of 2020: Visions of Engineering in the New Century*. The National Academies Press. DOI: https://doi.org/10.17226/10999

Paretti, M., Kotys-Schwartz, D., Ford, J., Howe, S., & **Ott, R**. (2020). Leveraging the capstone design experience to build self-directed learning. *International Journal of Engineering Education*, *36*(2), 664–674. https://www.ijee.ie/1atestissues/Vol36-2/14_ijee3903.pdf

Paretti, M. C. (2006). Audience awareness: Leveraging problem-based learning to teach workplace communication practices. *IEEE Transactions on Professional Communication*, *49*(2), 189–198. DOI: https://doi.org/10.1109/TPC.2006.875083

Paretti, M. C., & **McNair, L. D.** (2012). Analyzing the intersections of institutional and discourse identities in engineering work at the local level. *Engineering Studies*, *4*(1), 55–78. DOI: https://doi.org/10.1080/19378629.2011.652120

Pembridge, J. J., & **Paretti, M. C.** (2019). Characterizing capstone design teaching: A functional taxonomy. *Journal of Engineering Education*, *108*, 197–219. DOI: https://doi.org/10.1002/jee.20259

Riley, D. (2008). *Engineering and social justice: Synthesis Lectures on Engineers, Technology, and Society*. Morgan & Claypool. DOI: https://doi.org/10.2200/S00117ED1V01Y200805ETS007

Riley, D., Slaton, A., & **Pawley, A. L.** (2014). Social justice and inclusion: Women and minorities in engineering. In A. Johri & B. M. Olds (Eds.), *Cambridge Handbook of Engineering Education Research* (pp. 335–356). Cambridge University Press. DOI: https://doi.org/10.1017/CBO9781139013451.022

Ross, M. S., Huff, J. L., & **Godwin, A.** (2021). Resilient engineering identity development critical to prolonged engagement of Black women in engineering. *Journal of Engineering Education*, *110*, 92–113. DOI: https://doi.org/10.1002/jee.20374

Sheppard, S., Macatangay, K., Colby, A., & **Sullivan, W. M.** (2008). *Educating engineers: Designing for the future of the field*. Jossey-Bass Publishers.

Stevens, R., Johri, A., & **O'Connor, K.** (2014). Professional engineering work. In A. Johri & B. M. Olds (Eds.), *Cambridge Handbook of Engineering Education Research* (pp. 119–137). Cambridge University Press. DOI: https://doi.org/10.1017/CBO9781139013451

Streveler, R. A., Brown, S., Herman, G. L., & **Montfort, D.** (2014). Conceptual change and misconceptions in engineering education: Curriculum, measurement, and theory-focused approaches. In A. Johri & B. M. Olds (Eds.), *Cambridge Handbook of Engineering Education Research* (pp. 83–102). Cambridge University Press. DOI: https://doi.org/10.1017/CBO9781139013451.008

Streveler, R. A., Litzinger, T. A., Miller, R. L., & **Steif, P. S.** (2008). Learning conceptual knowledge in the engineering sciences: Overview and future research directions. *Journal of Engineering Education*, *97*(3), 279–294. DOI: https://doi.org/10.1002/j.2168-9830.2008.tb00979.x

Strimel, G. J., Bartholomew, S. R., Purzer, S., Zhang, L., & **Ruesch, E. Y.** (2021). Informing engineering design through adaptive comparative judgment. *European Journal of Engineering Education*, *46*(2), 227–246. DOI: https://doi.org/10.1080/03043797.2020.1718614

Svihla, V., Peele-Eady, T., & **Gallup, A.** (2021). Exploring agency in capstone design problem framing. *Studies in Engineering Education*, *2*(2), 96–119. DOI: https://doi.org/10.21061/see.69

Swenson, J. E., Johnson, A. W., Chambers, T. G., & **Hirshfield, L.** (2019). Exhibiting productive beginnings of engineering judgment during open-ended modeling problems in an introductory mechanics of materials course. *2019 ASEE Annual Conference & Exposition*, Tampa, Florida. https://strategy.asee.org/32786. DOI: https://doi.org/10.18260/1-2--32786

Ternes, M. E. (2019). Legal liability, good engineering judgment and adaptation. *Process Safety Progress*, *38*(3), e12083. DOI: https://doi.org/10.1002/prs.12083

Tonso, K. L. (2006a). Student engineers and engineer identity: Campus engineer identities as figured world. *Cultural Studies of Science Education*, *1*(2), 273–307. DOI: https://doi.org/10.1007/s11422-005-9009-2

Tonso, K. L. (2006b). Teams that work: Campus culture, engineer identity, and social interactions. *Journal of Engineering Education*, *95*(1), 25–37. DOI: https://doi.org/10.1002/j.2168-9830.2006.tb00875.x

Tonso, K. L. (2007). *On the outskirts of engineering: Learning identity, gender, and power via engineering practice*. Sense Publishers. DOI: https://doi.org/10.1163/9789087903534

Trevelyan, J. (2010). Reconstructing engineering from practice. *Engineering Studies*, *2*(3), 175–195. DOI: https://doi.org/10.1080/19378629.2010.520135

Trevelyan, J. (2014a). *The making of an expert engineer*. CRC Press. DOI: https://doi.org/10.1201/b17434

Trevelyan, J. (2014b). Towards a theoretical framework for engineering practice. In B. Williams, J. Figueiredo & J. Trevelyan (Eds.), *Engineering practice in a global context: Understanding the technical and the social* (pp. 33–60). CRC Press/Balkema. DOI: https://doi.org/10.1201/b15792

Trevelyan, J., & **Williams, B.** (2018). Value creation in the engineering enterprise: An educational perspective. *European Journal of Engineering Education*, 1–23. DOI: https://doi.org/10.1080/03043797.2017.1421905

Tversky, A., & **Kahneman, D.** (1981). The framing of decisions and the psychology of choice. *Science*, *211*(4481), 453–458. DOI: https://doi.org/10.1126/science.7455683

Vick, S. G. (2002). *Degrees of belief: subjective probability and engineering judgment*. ASCE Press, Reston, VA.

Weedon, J. S. (2016). Judging for themselves: How students practice engineering judgment. *2016 ASEE Annual Conference & Exposition*, New Orleans, Louisiana. DOI: https://doi.org/10.18260/p.25509

Weedon, J. S. (2017). Putting engineering judgment in conversation with engineering communication. *2017 IEEE International Professional Communication Conference*. DOI: https://doi.org/10.1109/IPCC.2017.8013977

Weedon, S. (2019). The role of rhetoric in engineering judgment. *IEEE Transactions on Professional Communication*, *62*(2), 165–177. DOI: https://doi.org/10.1109/TPC.2019.2900824

Wilde, R. J., & **Guile, D.** (2021). Client-facing interprofessional project teams: The role of engineers' "situated judgment". *Engineering Studies*, *13*(3), 185–204. DOI: https://doi.org/10.1080/19378629.2021.2005073

Williams, B., & **Figueiredo, J.** (2014). Finding workable solutions: Portuguese engineering experience. In B. Williams, J. Figueiredo & J. Trevelyan (Eds.), *Engineering Practice in a Global Context: Understanding the Technical and the Social* (pp. 159–184). CRC Press/Balkema. DOI: https://doi.org/10.1201/b15792

Willis, P. (1977). *Learning to labor: How working class kids get working class jobs*. Columbia University Press.

Winsor, D. A. (1988). Communication failures contributing to the *Challenger* accident: An example for technical communicators. *IEEE Transactions on Professional Communication*, *31*(3), 101–108. DOI: https://doi.org/10.1109/47.7814

Winsor, D. A. (1990). The construction of knowledge in organizations: Asking the right questions about the *Challenger*. *Journal of Business and Technical Communication*, 4(2), 7–20. DOI: https://doi.org/10.1177/105065199000400201

Yang, D., Streveler, R., Miller, R. L., Senocak, I., & **Slotta, J.** (2020). Using schema training to facilitate students' understanding of challenging engineering concepts in heat transfer and thermodynamics. *Journal of Engineering Education*, *109*(4), 743–759. DOI: https://doi.org/10.1002/jee.20360

TO CITE THIS ARTICLE:
Francis, R. A., Paretti, M. C., & Riedner, R. (2022). Theorizing Engineering Judgment at the Intersection of Decision-Making and Identity. *Studies in Engineering Education*, 3(1): 79–98.

Submitted: 15 March 2022
Accepted: 28 September 2022
Published: 14 November 2022