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# Engineering Judgment and Decision Making in Undergraduate Student Writing

**Dr. Royce Francis, George Washington University**

Dr. Royce Francis is an Associate Professor in the Department of Engineering Management and Systems Engineering [EMSE] at the George Washington University. At George Washington, Dr. Francis studies decision-analytic sustainability measurement in infrastructure systems, risk- and resilience-informed management of infrastructure systems, and the intersection of engineering judgment with engineer identity.

**Dr. Marie C. Paretti, Virginia Polytechnic Institute and State University**

Marie C. Paretti is a Professor of Engineering Education at Virginia Tech, where she directs the Virginia Tech Engineering Communications Center (VTECC). Her research focuses on communication in engineering design, interdisciplinary communication and collaboration, design education, and gender in engineering. She was awarded a CAREER grant from the National Science Foundation to study expert teaching in capstone design courses, and is co-PI on numerous NSF grants exploring communication, design, and identity in engineering. Drawing on theories of situated learning and identity development, her work includes studies on the teaching and learning of communication, effective teaching practices in design education, the effects of differing design pedagogies on retention and motivation, the dynamics of cross-disciplinary collaboration in both academic and industry design environments, and gender and identity in engineering.

**Dr. Rachel Riedner, George Washington University**

Rachel Riedner is Associate Dean of Undergraduate Studies and Professor of Writing and of Women's, Gender, and Sexuality Studies at the George Washington University, Washington, DC, USA.

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## Abstract

The exploration of engineering judgment in undergraduate education should be grounded at the intersection of decision making, situated cognition, and engineering identity production. In our view, engineering judgment is an embodied cognitive process that is situated in written and oral communication, involved with immediate praxis, and takes place within the contexts of standards and traditions of the engineering communities of practice. In our view, engineering judgment is constituted as authoritative communication tasks that draw on the subject's and audience's common experiences and knowledge base for its clarity and persuasive power. The objective of this work is to review the engineering education literature with the aim of synthesizing the concept of engineering judgment from theories of decision making, identity, communities of practice, and discourse identity. Although the rationale for developing engineering judgment in undergraduate students is the complexity they will face in professional practice, engineering educators often considerably reduce the complexity of the problems students face. Student work intended to train engineering judgment often prescribes goals and objectives, and demands a one-time decision, product, or solution that faculty or instructors evaluate. The evaluation process might not contain formal methods for foregrounding feedback from experience or reflecting on how the problem or decision emerges; thus, the loop from decision to upstream cognitive processes might not be closed. Consequently, in this paper, our exploration of engineering judgment is guided by the following questions: How have investigators defined engineering judgment? What cognitive processes do students engage to make engineering judgments? How do communication tasks shape students' engineering judgments? Finally, how is engineering judgment shaped by engineer identity?


## 1. Introduction

Beginning with the 2019-2020 academic year, ABET [1] added the ability to "use engineering judgment to draw conclusions" (p. 6) as an explicit outcome for graduates of engineering programs. Notably, while engineering judgment has been an implicit component of curricula for many years, little research has been done to date to define more concretely what the term means or how students develop engineering judgement in undergraduate education. This gap in turn complicates our ability to assess engineering judgement as a learning outcome or design effective pedagogies to help students learn it. To address this gap, we present a review of relevant research to develop a working definition and identify links between engineering judgment, situated cognition, and identity production as a step toward informing engineering pedagogy. We argue that the exploration of engineering judgment should be grounded at the intersection of decision making, cognition, and identity because, as the literature suggests, engineering judgment is reflected in the decisions engineers make throughout their work, depends on cognitive processes of both individuals and groups, and is embodied in authoritative professional communication tasks. These communication tasks draw on the subject's and audience's common experiences, shared disciplinary language, and knowledge base for their clarity and persuasive power, but they also depend heavily on the identity of the speaker as perceived both by self and others. Our exploration of engineering judgment is initially guided by the following questions:

1. How has engineering judgment been defined by researchers?
2. What types of cognitive processes constitute engineering judgment?
3. How is engineering judgment shaped by engineering identity?

## 2. What is Engineering Judgment?

ABET's addition of engineering judgment to the student outcomes required for accreditation positions this judgement as a practice subsequent to analysis and interpretation. Specifically, in the latest criteria, ABET expanded one of the student outcomes from "an ability to design and conduct experiments, as well as to analyze and interpret data" ([2], p. 3) to "an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions" ([1], p. 6). This shift implies that engineering judgment moves beyond the ability to make meaning ("interpret") from information to the ability to act - or communicate suggested actions - based on that meaning. And notably, while judgment is explicit with respect to drawing conclusions, it is also implicit in the addition of "appropriate" to describe the types of experimentation one designs and conducts. This shift - implicitly linking engineering judgment to action - suggests that decision-making is a useful point of departure for exploring engineering judgment. In this context, we define decision-making, loosely, as the connected processes that link perception (ABET's "interpretation of data") to action (the resulting conclusion).

### *2.1 Engineering judgment as decision making and cognition under complexity*

Broadly, decision making can be considered in two categories: open-loop (no feedback to inform formulation of goals and other processes informing selection of actions) and closed-loop (feedback from performance of action to iteratively refine the configuration of the processes upstream of selection of actions) [3]. From this perspective, engineering judgment is a closed-loop, naturalistic decision-making process. The defining characteristics of a closed-loop naturalistic decision process, compared with an open-loop process, is the presence of feedback, uncertainty, ambiguity, and conflicting objectives. It is important here to distinguish between the type of process (closed or open loop) and the type of problem, which engineering education research often groups broadly into open-ended and closed-ended (e.g., [4]). All decision making involves the kind of open-ended problems that are central to engineering practice - the very openness is, in fact, what requires a decision. Closed-loop processes are those that incorporate feedback; such feedback is a central feature of classic representations of engineering design and problem-solving, where these processes are consistently portrayed as iterative based on testing and evaluation.

When considering prior engineering education research on engineering judgment, the context described by researcher and educator resembles a closed-loop, naturalistic, decision making process much more than an open-loop process. For example, engineering education researchers exploring engineering judgments faced by students often document:

- incomplete rather than complete information;
- ambiguous specifications rather than clear requirements;
- uncertainty about operational performance rather than certainty in projections; and,
- augmented memory or information processing through interaction with external sources, tools, and experts rather than complete and adequate internal memory.

The interaction among these characteristics yields complex, potentially poorly structured problems—having poor data quality, ambiguity, and high-stakes. Thus, developing engineering judgment in order to make decisions in the face of complexity is an important educational objective. Prior research suggests that decision making under complexity involves several interacting cognitive processes including but not limited to: perception (reception or collection of information from the natural, social, or operational environment), memory (storage, organization, and retrieval of the perceived information), judgment (transformation of the perceived and stored information into meaningful alternatives), choice (evaluation and selection from among these meaningful alternatives on their merits), feedback (knowledge of outcomes obtained from prior judgments and actions), and learning (reinforcement of the consequences of past decisions)

Many investigators' conceptions of engineering judgment can be considered adaptations of the closed-loop view of decision making. For example, Douglas et al. [5] and Wait et al. [6] approach engineering judgment in engineering education as the skill of solving open-ended problems characterized by uncertainty. In both investigations, open-ended problems are defined as potentially ill-defined, ambiguous, potentially lacking critical information, having many potential solutions, and multiple potential courses of action to reach these solutions. Open-ended problem solving, i.e., engineering judgment, then, is the ability to navigate the complexity of open-ended problems. Paretti et al. [7] defines engineering judgment as students' ability to weigh costs and benefits to select among competing options based on disciplinary values and stakeholders' values. Pantazidou and Nair [8] describe this as an "ethic of care" and draw on an example of a vertical lift bridge design case to illustrate these dynamics. Shaw et al. [9] explore these challenges in software engineering, arguing that the challenge of balancing stakeholder concerns and values while also managing their (stakeholders') increased participation in the creation of the software requires this type of engineering judgment up front. Although the term "engineering judgment" is not used by Shaw et al., their work indicates that failing to address these challenges effectively at the beginning stages of design can lead to dramatically increased costs later on. Siewieorek et al. [10] construct the concept of "reflective judgment" that captures some of the ways students construct these judgments incorporating multiple criteria using a grounded theory investigation. Their findings resonated with King and Kitchener's reflective judgment model [11] (pre-reflective reasoning, quasi-reflective reasoning, reflective reasoning) as being descriptive of students' growth in reflective judgment. Additionally, these investigations into engineering judgment highlight the role of social responsibility in amplifying the challenges presented by ambiguity and conflicting interests in many types of open-ended problems faced by engineers.

Although most of these works investigate engineering judgment as something an individual does, it is equally important to consider the work of engineering judgment as something done *among* groups of individuals or *by* groups of individuals to negotiate complexity, reflecting patterns of distributed cognition. Engineering judgment, embedded in design and problem-solving, is a thoroughly social process [4], [12] that may be the primary performative practice through which an engineer participates in the profession. For example, Weedon [13]–[15] investigates engineering judgment as the enacted and embodied communication processes that are situated among teams of engineers. In that study, engineering judgment is conceptualized in part as the ability to recognize the rhetorical tactics required to satisfy an 'emergent' task. Similarly, Trevelyan [16] explores engineering work as distributed cognition enacted through social interactions. Both investigators frame engineering judgment not as something done by individuals, but as a process that can either take place within individuals or between individuals - and which takes place in and through language. In related work, Cristancho et al. [17], investigating medical judgment, also informs our understanding of the ways judgment emerges from the interaction of complex components of a decision context. In their exploration, medical judgment is not an isolated step in 'problem solving' but is something that emerges as the expert's conceptualization and understanding of the problem evolves through their interactions with other medical team members and is enacted through improvisation in the operating environment. The parallels between medicine and engineering as professions (and the recent merging of the two in fields such as biomedical engineering) suggest that engineering judgment could operate similarly.

Engineering judgment as decision making under complexity, then, is mediated through situated cognition. The situated cognition view of learning asserts that cognition is embodied in human practice. A classic example of situated cognition is presented in Lave [18] where she reports the results of a study of individuals who may have some difficulty solving traditional math problems involving fractions, but have much less difficulty solving analogous problems when they involve recipes and grocery shopping. The ease of the fractions calculations in the context of the practice (i.e., grocery shopping and cooking) is attributed to the embodied nature of the tasks facilitating the arithmetic computation. Situated cognition is closely linked to the communities of practice theory of learning. At the broad level situated cognition serves to describe the ways in which humans may be much better at learning and performing cognitive tasks situated in a naturalistic or practice-based environment than in an abstract, decontextualized one. In terms of learning specifically, communities of practice extends the concept of situated cognition to frame learning as something that happens when individuals are engaged in authentic tasks amid a community of individuals characterized by a joint enterprise, mutual engagement, and a shared repertoire of tools and discourse [19].

Thus, in this view, engineering judgment could be seen as the ability to successfully use engineering tools (e.g., software, codes, etc.) in engineering work settings to communicate the engineering work in ways that the communicator is recognized as a member of the community of practice. The tools are implied by the situated cognition perspective. Obviously, engineering is embodied practice, requiring fluency in a range of tools and techniques that greatly expand the types of work individual engineers can produce. The communication and recognition is implied by the communities of practice perspective.

### *2.2 Engineering judgment as engineering thinking and learning*

While engineering judgment can be envisioned as closed-loop decision-making, what distinguishes it from such decision-making in other fields is both the knowledge base and the set of interpretive practices engineers draw on when making decisions. That is, it reflects both what engineers learn and the ways they learn to apply and interpret that knowledge in specific contexts. For example, Gainsburg [20], relates engineering judgment to deep domain and mathematical knowledge about physical phenomena tied to physical interpretations. In engineering education, investigators and instructors employing this notion of engineering judgment explore how best to assist students in developing these reasoning capabilities. For example, MacRobert [21] defines engineering judgment as students' ability to apply common sense and proportion to design. Students use their experiences and physical knowledge to determine whether calculations or predictions make sense. Swenson et al. [22] investigated the use of open-ended mathematical modeling problems to develop this type of judgment--the ability to determine the reasonableness of the analysis or design. Wagh [23] and Parkin [24] also employ a similar definition, referring to engineering judgment as a 'quasi-rational' combination of analysis and intuition that enables engineers to incorporate computational and other tools into their work. Claris and Riley's [25] work suggest metacognitive practices might aid in developing these patterns of thinking in students. Claris and Riley [25] adapt Pierce's model of engineering judgment based on reflection. Resembling metacognition, this engineering judgment model is a continuum from non-reflective to meta-cognitive. At the reflective and meta-cognitive levels, students use multiple observations and experientially informed reasoning to make connections and achieve knowledge transfer across conceptual areas. Their findings might hint towards a systematic curriculum-wide approach to connecting across concepts, courses, and sub-disciplines to foster this quasi-rational combination of analysis and intuition.

The idea that engineering thinking and judgment is a quasi-rational combination of analysis and intuition can be extended to professional practice by considering: i.) the ways practicing engineers interact with computational tools and techniques that facilitate their work; and, ii.) how traditional professional judgments can be reified in common design practices such as standards, safety factors, or policies and regulations. Bruhl et al. [26] explore the former, noting that engineering judgment is the higher-level thinking tasks employed in design thinking that complement computer-aided tasks such as computation. For Bruhl et al. [26], this thinking is primarily the ability to recognize or predict the probable outcome of an analysis, design, or process. Briefly, we will also note here that engineering judgment--or at least the development of engineering judgment--is a process that implies engineering learning since the engineer's experience shapes and is shaped by the process of developing engineering judgment through feedback. Selim et al [27] explore the latter, suggesting that engineering judgment may be encoded using heuristics that embody engineering and physical experience for the purpose of design. As these physical experiences become increasingly common--or to the extent that it is convenient to have a common representation of these embodied experiences--engineering judgment can be canonized or reified for a community of practice in a document of standards. In fact, insights from the work of Wenger [19] indicate that the practice of engineering judgment and the ways that engineering judgment might be canonized could be important markers of the boundary of the community of practice. Shapiro [28] also explores this idea that standards embody collective physical experience by describing standards as the accumulated "embodiment of judgments rendered by a particular community of practice" (an instance of Wenger's concept of 'shared repertoire' [19]) and acknowledges that standards reflect and shape practitioner judgment.

*2.4 Summary*

In summary, engineering judgment has been considered in several ways in the literature. Most often, engineering judgment is something that individuals do based on their technical training and consideration of objective facts available to them. Most engineering judgment studies acknowledge the subjectivity or negotiation of different perspectives involved in engineering practice, especially pertaining to tradeoffs between stakeholder perspectives, client or business needs, and technical theory or constraints. Additionally, engineering judgment is a defining characteristic of engineering practice and professionalism. Nonetheless, the study of engineering judgment has under-explored the conceptualization of engineering judgment as: i) engineering cognition (i.e., the way engineers think); and ii) the way engineers become socialized into the profession. iii) the ways in which judgement happens in and through language, particularly writing. In the next two sections, we propose points of departure for these conceptualizations and propose potential research avenues that could help to illuminate the role of engineering judgment in student writing.

## 3. Engineering Judgement and Engineering Identity

Finally, in addition to understanding the cognitive processes that underlie the process of making engineering judgments, researchers and educators need to consider the ways in which students' identities enable or constrain them as they implement or enact those judgments, particularly in collaborative contexts. That is, as situated perspectives on learning make clear [29], learning is not only the acquisition of knowledge and skills, but also the transformation of identity. To exercise engineering judgment, students must come to see themselves not only as individuals who can apply procedural knowledge to analyze data, or even draw on conceptual knowledge to make meaning from those analyses, but as people who have the authority to use those meanings to legitimately decide (or at least recommend) courses of action and successfully communicate their authority to stakeholders.

We can conceptualize this authoritative identity as the ethos of engineers, that which gives them credibility in the decision-making process - in their own eyes as well as in the eyes of others. One source of this authority is engineers' ability to access mathematical and physical knowledge and draw on theoretical analysis to interpret or make sense of information in ways that may not be accessible to others. While this ethos is often represented as an ideal of the dispassionate, objective professional who crafts arguments and makes decisions supported by objective facts and irrefutable physical evidence, in practice, as the preceding discussion of cognition suggests, engineering judgement reflects a reasoned interpretation of an ambiguous situation. Thus, the ability to embody and be perceived as an authority is particularly important 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. The judgments of seasoned engineers are critical when the data or prevailing theory do not otherwise exist or are poorly formed to the problem at hand.– contexts that, as Jonassen argues, dominate professional engineering work [4]. For example, in investigating environmental policy, House et al. [30] frame engineering judgment as discharging technical expertise in the service of potentially incommensurate political or economic interests and goals in environmental policy. In their framing, the credibility and the authority of the expert is derived from their ability to acknowledge that the technical expertise is not disinterested. Moreover, they argue that the most credible engineering experts capably negotiate the political and economic factors that might otherwise derail the regulatory apparatus. Another field that illustrates the authoritative appeal of the engineering ethos is probabilistic risk analysis. Baybutt [31] studies the role of engineering judgment in subjective risk analysis where low-probability, high-consequence events are dominate. Under these scenarios, because most of the events concerned are often either not repeatable or unobservable, the subjective authority of the engineering expert substitutes for empirical observation of system vulnerability or failure. In these scenarios, it is not guaranteed that the authority of the engineering ethos will be accepted, so engineers must develop rhetorical techniques that might increase the likelihood they will be perceived as authoritative. For example, Lynch and Kline [32] explore a technocratic model of engineering judgment in their re-analysis of the Challenger accident; one of the critical issues the engineers in that incident faced was their inability to be perceived as – that is, to embody the identity of – an authority with respect to the decision to launch. Ternes [33] explores the evolving role of engineering judgment in climate adaptation, arguing in part that legal liability for damages attributable to climate change could be of increasing importance to chemical engineers because these damages should be increasingly foreseeable. Here, too, engineers' ability to both see themselves and be perceived by others as an authority is essential having one's judgements accepted by others.

For educators, then, the question becomes how do we enable students to begin building this identity, to begin to see themselves and be seen by others as professionals who are not simply human calculators churning out correct answers to complex mathematical equations or demonstrating sufficient proficiency with computer-aided design software? In part, the answer is that one's engineering ethos is built through time and experience; perhaps without ABET specifying engineering judgement as a required student outcome, we might be tempted to claim that graduating engineers cannot possess sufficient experience to exercise engineering judgment or to claim that identity position. Moreover, studies of new engineers at work demonstrate that even in the first months of their career, new engineers are asked and expected to make judgements and recommend action [34]. Thus, if engineering education is to be more than a vocational school training we must think critically about how the undergraduate education can facilitate acquisition of sufficient experience to claim that identity position.

Because engineering judgements are represented in and through written language – in reports, presentations, emails, discussions, and so on – we turn to the concept of discourse identity as a productive approach to this challenge. Gee [35] defines identity as "being recognized as a certain 'kind of person'"(p. 99), and discourse identity in particular as the identity that emerges and is sustained through dialogue (written or oral). Allie et al. [36] argue that the acquisition of a discursive identity is central to learning to be engineering; following their work, we argue that it is central to the development of engineering judgement in particular. Moreover, drawing on theories of academic and disciplinary literacy, we suggest that writing is one key site for helping enabling students to develop this identity. First, however, we situate the development of engineering identity in the larger context of campus cultures using Tonso's work on the cultural production of engineering identities [37], [38].

### *3.1 Engineering judgment as engineer identity production*

Drawing on the work of Willis [39], Holland et al. [40], and others, Tonso [37], [38] 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 engineering project teamwork. Tonso ([38], p.273-274) describes engineering identity production as "a complicated process that bound up thinking about oneself as an engineer, performing an engineer self, and ultimately being thought of as an engineer." Tonso focuses on the social and institutional features that form the backdrop within which students perform, or produce, their engineering identities. Her work reframes the focus away from engineering identity as a characteristic or feature held by an individual and towards 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. Most prior research, as noted above, treats engineering judgment as something *individuals* do or possess. Cultural production theory, in contrast, suggests that to enact engineering judgment, individuals must construct meaningful identities (ethos) within the constraints and affordances of their local cultures. Engineering judgment is a cultural form that engineers produce to be recognized from within or as part of a certain type of culture. Identity production is informed by cultural production theory, where "socially situated 'texts' or 'forms'" are negotiated or contested among the individuals in a community ([38], p.278).

At the same time, cultural production theory highlights the ways in which engineering judgment, and the corresponding identities individuals construct, are mediated among groups of engineers, rather than something an individual performs or possesses in an abstract or isolated sense. That is, the ability to enact engineering judgment is contingent on the identities made available by the existing local cultures; in Gee's words, one must "be recognized" by others as someone whose judgements are to be trusted. This link between available identities and acceptance of judgement is apparent throughout Tonso's work as she explores whose judgements are accepted and sought – within design teams, by faculty advisors, among peers [37], [38], [41].

This framework has critical implications for educators who seek to build students' engineering judgement because is asks to step back and consider the ways in which, through our assignments and teaching practices, we do and do not make available the identities students need to enact engineering judgement.

### *3.2 Engineering judgment as the acquisition of disciplinary literacy*

Here, we suggest that one of the ways educators can make relevant identities available is through providing them with access to and opportunities to enact the discourses of engineering judgement. As noted earlier, Allie et al [36]. argue that the acquisition of a discursive identity is central to engineering learning – that is, learning to be an engineer is deeply linked to learning to talk and write like an engineer. Importantly, this "talk" is not simply a matter of acquiring the "right" jargon; it is about certain ways of using language, acting, interacting, behaving, using tools, sign systems, as well as understanding the acceptable forms of data, information, reasoning, and practice that are central to engineering work. More specifically, developing engineering judgement is not simply the process of acquiring enough knowledge, but understanding how that knowledge is used to interpret and decide, and how those interpretations and decisions are made visible through language in ways that enact the identity needed to exert meaningful authority. The cognitive processes highlighted in section 2 must also be enacted or embodied through language, in dialogue (written or spoken) with others such that engineering judgement can guide action.

Broadly, this view of learning reflects what scholars such as Lea and Street [42], drawing on a body of work within writing studies called 'New Literacy Studies,' refer to as academic literacy, which treats learning to read and write in a given field as a socialization process through which students acquire and synthesize knowledge within their new discipline. That is, learning to write is not simply a process of acquiring skills in, say grammar or organization, but rather is a way of understanding the epistemologies and social practices of a discipline. They argue, as well, that disciplinary literacy practices are intertwined with issues of both identity and power, echoing the cultural production of identity seen in Tonso's work. Working along similar lines, Berkenkotter et al. [43], [44] trace the experiences of a new graduate student learning to write during his first year in a doctoral program. Their study illuminates the ways in which writing reflects disciplinary ways of knowing, reasoning, and arguing. Moreover, their research, along with the work of Lea and Street and others, reflect the ways in which this acquisition of academic or disciplinary literacy is also a process of identity transformation, as suggested by Gee's foundational notion of discourse identity.

While the concept of disciplinary literacy applies broadly across student learning within engineering (and other disciplines), we argue that it has particular resonance for the development of engineering judgement. As argued in previous sections, engineering judgement involves closed-loop decision making in the face of ambiguous or open-ended problems, drawing on domain-specific knowledge of mathematics and science as well foundational engineering principles. But these judgements only become actionable when individuals can share them with others in ways in which their authority is recognized. Thus, *while it is important to help students develop the appropriate cognitive processes that support decision making, it is equally important to help them communicate in ways that enable them to both see themselves and invite others to see them as engineers qualified to make such judgements*. Moreover, disciplinary literacy and discourse identity, as theoretical frameworks, make it clear that such communication practices are not merely skills, but sites of deep learning and identity development [42], [43].

This perspective implies that it is essential for engineering programs to provide opportunities to develop engineering judgement, making and justifying decisions in a range of contexts. Notably, the practice of justifying decisions using engineering reasoning was one of the outcomes identified by Paretti et al. [7] in their study of engineering learning associated with integrated writing programs. Though it does not explicitly highlight the term "engineering judgement," that study highlights the ways in which writing assignments that ask students to not only engage in open-ended problem solving, but persuade others regarding the soundness of their judgements, helps build students' capacity to reason along disciplinary lines, drawing on knowledge and modes of thinking that are characteristic of and acceptable to the community.

## 4. Conclusions

At the outset, our objective was to explore the concept of engineering judgment guided by questions of how prior investigators have defined engineering judgment, and how engineering judgment intersects with the development of professional identity. Our consideration of these works suggests some productive possible avenues of further development for classroom practice by engineering educators.

First, we demonstrated that the research on engineering judgment often involves decision making. Engineering educators who aim to develop engineering judgment may consider guiding students to grapple with problems where they face incomplete rather than complete information, ambiguous specifications rather than clear requirements, uncertainty about how their designed systems might perform, and authentic interaction with external sources, tools, and experts. Engineering educators might consider how to design assignments and experiences that help students to engage the process of making decisions. Assignments and classroom activities are as much about the process that involve integrating feedback, reflecting on the problem, changing understanding of what the problem is, dealing with uncertainty and ambiguity, and iteratively moving towards a solution as they are about the ability to understand and apply knowledge.

Second, the role of identity and social situatedness in developing skill in engineering judgment must not be under appreciated. Researchers and educators need to consider the ways in which students' identities enable or constrain them as they implement or enact those judgments, particularly in collaborative contexts. Engineering judgement is about learning to work through complexity and act; this includes how engineers do work through complexity and act in social groups and in and through written language. Assignments and classroom practice should create situations in which students can come to see themselves as professionals who make decisions about complex problems within social groups and in and through language. Furthermore, assignments and classroom instruction combine with extracurricular experiences and campus culture to facilitate acquisition of engineering identity.

Finally, engineering educators must consider how we might enable students to begin building professional engineering identity, that is, to begin to see themselves and be seen by others as professionals who are not simply human calculators churning out correct answers to complex mathematical equations or demonstrating sufficient proficiency with computer-aided design software. Our review of the literature suggests we must think critically about the types of experiences the undergraduate education should incorporate to facilitate acquisition of sufficient experience to confidently practice engineering judgment from a position of professional authority. Students must understand how their knowledge is used to formulate and work through complex problems, interpret, and make decisions, and how these interpretations and decisions are authoritatively made visible through shared language of their academic and professional disciplines. Moreover, students must understand that it is critical to learn to use language that is authoritative to different audiences. Communication practices such as writing and oral communication are not merely skills that are tangential to engineering knowledge, but are themselves sites of technical learning, knowledge production, and engineering identity development.

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