Examining the Engineering Leadership Literature: Community of Practice Style

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Abstract

Inherent to the career trajectories of professional engineers is an expectation that they learn to integrate communication, interpersonal and leadership skills into their technical knowledge base. While this process may feel smooth and natural to some, research suggests that others find it challenging and require support [1-3]. Our paper examines three bodies of literature relevant to engineering leadership learning in industry contexts: industry perspectives on the skills, traits and styles of effective engineering leaders; large-scale surveys tracking engineers' career paths and transitions; and ethnographic studies examining engineers' professional identity development. Our primary reason for doing this is to ground the next phase of our engineering leadership project in the literature. In addition to this project-specific goal, we use the paper to document the collective, interdisciplinary process we used to review the literature. We begin by identifying our search criteria and fleshing out three key themes in the literature. We then analyze the themes through a conceptual framework made up of four theoretical tensions relevant to leadership learning: leadership as a position/process; social action shaped by human agency/social structure; learning as a situated/formal endeavour; and social justice as a central/peripheral concern. After discussing the significance and limitations of our inter-disciplinary literature review experiment, and highlighting a gap in the leadership learning research, we generate a list of recommendations for engineering educators, industry leaders and engineering leadership researchers.

Introduction: Reviewing the literature CoP (community of practice) style

Lave and Wenger's notion that workplace learning takes place in a *Community of Practice* (CoP) helped us characterize our collaborative literature review experiment as a simultaneous process of learning and professional socialization [4]. A summer reading group—initiated by our Director and Senior Research Associate—began with two objectives: 1) to generate a literature review for the next phase of our engineering leadership project and 2) to build cohesion in our expanding, interdisciplinary research team. We sent out invitations to five individuals, all of who agreed to join our community of readers. Our group consisted of two engineering professors, three social science researchers, a staff member responsible for industry connections, and an undergraduate industrial engineering thesis student. We held six, two-hour meetings between July 13th and October 4,th 2017 involving guided discussion of seven articles selected by group members in attendance. The first meeting functioned as a capacity building orientation—allowing us to share the objectives of our reading group and practice using our reading guide as a platform to discuss engineering leadership research. The remaining five meetings consisted of guided article reviews, a discussion of key findings, and a conceptual mapping exercise. Each group member identified, read and led a discussion of one article each week, then participated in our group mapping exercise. The facilitator read all articles identified by group members, synthesized findings between meetings, and disseminated these findings to members for review. At the end of each meeting we collectively identified gaps in our growing conceptual map and key words for further exploration. Please see Table 1 for our selection criteria. In contrast to traditional literature reviews that come to a close once the reader has reached a conceptual saturation point, we stopped reading after completing the pre-determined six two-hour meetings.

Table 1: Literature review search criteria

Meeting Number	Selection Criteria	Rationale	Selected & led by	Read by
1	3 key engineering leadership articles	Orient members to engineering leadership literature and reading guide.	Facilitator	All
2	Keywords: "engineer" AND "leadership"	Bridge disciplines. All articles must address leadership in an engineering context.	7 reviewers	Each reviewer reads/leads his/her selection. Facilitator reads all 7, leads 1.
3	Engineering leadership in workplace contexts	Much of the leadership learning literature is set in university contexts, but our research will take place in industry.	7 reviewers	Same as above.
4	Keywords: "engineer" AND "leadership" AND "learning" in workplace contexts	Much of the engineering leadership literature that is set in industry contexts treats learning as a black box.	7 reviewers	Same as above.
5	Learning theory applied to engineering	Gap remains—since we had a difficult time identifying engineering leadership learning research set in industry contexts, we decided to leave the combined keyword search behind and identify highly relevant learning theory for our conceptual framework.	Facilitator	All
6	Keywords: "engineering leadership" OR "workplace learning"	Find high quality articles on at least one relevant domain.	7 reviewers	Same as 2-4.

Conceptual framework

A positive consequence of our decision to review the engineering leadership literature collectively was the thematic and methodological diversity of our findings. A corresponding disadvantage stemming from this diversity was the divergent nature of our review. We managed this divergence by examining three key bodies of literature through four analytic tensions drawn from theories on leadership, social action, situated learning and social justice. Please see Table 2 for a list of these theories, conceptual tensions and key authors. We chose these theories for two reasons. First, they conceptually underpin our research question—How do engineers learn to lead in industry contexts? And second, reading group members chose several of the texts informing this framework in response to weekly selection criteria. Our decision to integrate all selected articles into our literature review led us to separate those that were conceptually dense from those that were heavily content-based. Articles in the first group formed our analytic lens while those in the second became our focal point. In the paragraphs that follow, we flesh out the four conceptual tensions in our framework.

Table 2: Conceptual tensions

Theory	Conceptual tension	Key authors
Leadership	Position/Process	Komives; Bass
Social action	Structure/Agency	Archer; Billet
Learning	Situated/Formal	Lave & Wenger
Social justice	Central/Peripheral	Cech

First, many leadership theorists make a deliberate conceptual distinction between leadership and management—often framing management as the bureaucratic straw man against which leadership shines. Drawing on the work of Komives [5] and Bass [6], we locate this distinction in the source of an engineer's influence and authority. When an individual's authority is rooted primarily in organizational structures and is enacted through project planning, budgets, or company policies, we characterize it as "positional," following Komives, or "transactional," following Bass. When an individual's influence stems from his or her capacity to motivate and inspire others, and is less clearly derived from organizational policies or structures, we characterize it as "process-based," following Komives, or "transformational," following Bass. By using the position/process distinction in place of a leadership/management dichotomy, we honour the work of engineers who are in official management positions as well as those who influence others from a range of organizational locations.

Our second conceptual distinction relates to the first in its treatment of influence. Drawing on the work of Archer [7] and Billett [8], we recognize a continuum between researchers who characterize social action as a product of unmediated human agency and those who characterize it as a socially mediated phenomenon shaped by policies, practices, norms and structures. This conceptual tension between structure and agency is useful to us because it forces us to pay attention to organizational context—in particular, the facilitating and constraining forces at play as engineers learn to lead.

Honouring the centrality of leadership learning to our project, our third conceptual tension compares situated and formal learning opportunities experienced by engineers at work. We draw on Lave and Wenger's [4] situated learning theory to examine how engineers learn to lead. At the situated end of the continuum, we as what and how engineers learn about leading through their participation in a community of practicing engineers? At the formal end, we ask how they benefit from formal learning opportunities like leadership workshops, training sessions and classes? This analytic distinction between situated and formal learning helps us investigate how engineers learn to lead in their respective workplaces—institutions that are not specifically set up to teach them.

Our final conceptual tension is rooted in Cech's [9] research on social justice in engineering contexts. In particular, we ask whether engineering leadership researchers treat diversity as an additional topic or as a pre-existing, constitutive aspect of all social phenomena—including leadership. We have included this tension because our institute is dedicated to helping engineers lead change by building a better world, and more specifically because many of the articles selected by our reading group explicitly address diversity, inclusion or social justice. Together, these four conceptual tensions drawn from leadership, social action, situated learning and social justice theories allow us to gain analytic clarity on our otherwise divergent literature review.

Literature review: Engineers' leadership learning

Three key themes emerged from the engineering leadership literature we reviewed: 1) skills, traits and styles of effective engineering leaders, 2) engineers' career paths and transitions, and 3) engineers' professional identity development. We take up each theme in the subsections below addressing the problem statements used by authors to frame their research, the data sources they used to back up their arguments, key findings emerging from their research, and the implications of their findings for engineering leadership educators, human resource professionals and researchers.

Theme 1: Effective engineering leaders complement technical competence with social skills

Thirteen of the articles we reviewed examined the skills, traits and styles of effective engineering leaders. All but two were framed by a version of the following problem statement: the competitive global climate is leaving engineers with exclusively technical skills behind. The remaining two were framed by a call for leadership that was more responsive to engineers' professional needs. While these two problem statements are underpinned by different philosophical paradigms, authors whose work we have grouped together in this section advocate for a similar solution—help engineers develop the necessary skills, traits and styles to be effective leaders or managers. Two authors argued that managers of engineers should be responsive to the particular needs, personality types and learning styles of engineers [10, 11], two compared the leadership styles of engineering managers to non-engineering managers [12, 13], seven urged engineering leaders to develop their social, interpersonal and communication skills [14-20], and the remaining two warned us against characterizing engineers' leadership styles in a culturally neutral manner [21, 22].

The two authors who discussed effective leadership styles for managers working with engineers began by pointing out the distinctive nature of the engineering profession. Mallette's "Theory Pi," based on 30 years of observations during his career in the aerospace industry [10], urged managers to tailor their leadership approach to engineers' personalities and work habits. To be effective, he argued that engineering leaders should have strong technical skills, be hands off, resolve conflict using logical reasoning, base personnel assessments on project outcomes, and interact with engineers as equals. While Mallette's proposed theory might indeed result in effective engineering leaders, he did not test it with a group of engineers, nor did he test his assumption that the majority of engineers are Introverted, Intuitive, Thinking, Judgers (INTJ Myers Briggs personality type). Wyrick similarly characterized engineers as a distinctive group, but he did so based on data he collected over ten years in four engineering management cohorts in the United States and Sweden [11]. Using Kolb's Learning Style Inventory [23], he found that most engineering management students across national and disciplinary contexts were "convergers" who thrive on practical applications of ideas and are good at solving specific problems. Based on this finding, he urged managers to use specific strategies that would scaffold the learning of convergers. Like Mallette's theory Pi, Wyrick's engineering management strategy highlights the importance of being responsive to one's team members. Unfortunately, by depending on what may be a majority trend within the profession, both authors silence the voices, behaviours and contributions of engineers who break with these norms. They simultaneously reinforce normative behaviours in the majority.

In contrast to Mallette and Wyrick who wrote to an audience of managers hoping to effectively direct the work of engineers, Riley [13], Brown [12] and their respective colleagues studied the styles and personality attributes of engineers who were themselves leaders. Riley and Cudney conducted a small-scale, mixed-methods study on the leadership styles of engineering managers and non-engineering managers across technical industries in the United States and found that engineers were more likely than non-engineers to engage in defensive behaviours when encountering conflict. According to the authors, defensive routines are problematic because they inhibit a leaders' ability to learn, as well as to detect and correct errors. In a similarly structured study, Brown, Grant and Patton used leadership personality dimensions of the California Psychological Inventory to examine the personality traits of engineers, engineering managers and non-engineering managers working at high tech companies in Northern Utah. They found that relative to engineers and engineering managers, non-engineering mangers were more outspoken, socially oriented, confident, poised and competitive. While this study was published two decades before Mallette's and Wyrick' articles, and three decades before Riley and Cudney's work, it provides evidence for the hypothesis that engineers and engineering managers are less socially oriented than managers trained in other disciplines. Perhaps as a reaction to this persistent finding, the next seven studies are premised on the argument that engineers need to balance their technical training with interpersonal, communication and other social skill development opportunities.

Farr and his colleagues identified nine key professional skills and traits engineers need to develop if they would like to be effective leaders: "big thinker, ethical and courageous, masters change, risk taker, mission that matters, decision maker, uses power wisely, team builder and good communicator" [14, 24]. Joyner, Mann and Harris use empirical data to make a similar point. They analyzed personality inventory results of 1100 engineers and engineering managers working for a Fortune 500 company with American and European offices and found that, in the aggregate, engineers scored high on dominance, formality and objective decision-making and low on extroversion [17]. This finding supports Mallette's claim that INTJ (Introverted, Intuiting, Thinking, Judger) is a prevalent personality type among engineers. The authors use these findings to argue that emotional intelligence training would benefit engineers by helping them complement their technical skills with necessary social skills. Similarly, three papers written by Lappalainen focus on the importance of communication, socio-emotional and interpersonal skill development for engineers [18-20]. Based on a survey of 80 managers and 354 subordinates employed by seven engineering-intensive organizations in Finland, she found that emotional intelligence was a stronger predictor of effective engineering leadership than traditional analytic intelligence. She used this finding to argue that professional skills help engineers convert their technical content knowledge into profitability and productivity. Finally, Hartmann and her colleagues conducted a document analysis of 982 entry-level engineering job postings sent to the career centre of a university in the Midwestern United States. They learned that when industry representatives included the word "leadership" in their entry-level job postings, they were looking for individuals with strong communication, teamwork and interpersonal skills [15]. In a follow up study, they used these findings to generate a survey instrument, which they piloted with 172 recruitment contacts, and found that companies looking for entry-level engineers with leadership skills tended to prioritize initiative or confidence over other skills and traits [16]. Less highly rated skills that were still deemed important included: communication, interpersonal interactions, teamwork and engagement.

Finally, two of the articles we reviewed challenge the basic assumption underlying the effective leadership literature by examining the presumed neutrality of leadership styles, traits and skill sets deemed to be effective for engineers. Kuchinke examined the cultural values, leadership styles and personality traits of technical employees working at a multinational fortune 500 telecommunications company with offices in the United States and Germany [21], and found higher levels of individualism, charisma and masculinity in the American than German sample, with American employees scoring slightly higher than their German counterparts on transformational leadership. While the effect size was small, Kuchinke's findings caution us against presuming that transformational leadership is similarly valued across national contexts. Similarly cautioning us against generalizing notions of effective leadership across diverse groups, Sy et al. examined the unconscious racial stereotypes held by MBA students and industry professionals through three experimental studies [22], and found that participants held stereotypes about Asian Americans being more suited to engineering or technical work and Caucasian Americans being more suited to sales. When it came to leadership, participants were more likely to perceive Asian Americans as dedicated, technically competent leaders than as agentic leaders. Applying these findings to the effective leadership literature we reviewed above, if promotion committees perceive agentic or transformational leaders to be more effective than technically competent or transactional leaders, Caucasian American engineers may be promoted at higher rates than equally qualified Asian American or German engineers. These two articles suggest that our identification of "effective" leadership skills, traits and styles are infused with unconscious biases that may privilege some groups of engineers over others.

Authors of the thirteen articles we reviewed in this section examined engineering leadership effectiveness using experimental studies, large-scale surveys, and experientially based calls for change to argue that either managers need to adapt to engineers' technical-rational, convergent proclivities, or that engineers as managers need to develop a suite of professional skills to complement their technical training. Whether they viewed engineers as a homogenous group of professionals who must be accommodated, as technically trained individuals in need of social skills, or even as citizens with culturally diverse values, all thirteen researchers focused on the individual engineer or engineering manager as the primary unit of analysis. An important implication for engineering educators and corporate trainers is to integrate social skills training into otherwise technical learning opportunities. As engineering leadership researchers, an important implication for us is to unpack the implicit biases in our notions and ascriptions of leadership effectiveness. Returning to our research question, the effective engineering leadership literature frames leadership as a set of skills, traits and styles that can be learned by engineers across organizational locations and career paths. Unfortunately, it sheds limited light on how engineers actually learn to lead or develop leadership skills in industry contexts.

Theme 2: There are more than two engineering career paths

Ten of the articles we reviewed focussed on the career trajectories of engineers, many of them touching on a particular transition point—the early to mid career shift from technical to managerial work. The authors of these papers tended to frame the problem in organizational terms. In particular, they argued that the dual track model of engineering mobility failed to reflect engineers' considerably more hybrid and malleable workplace realities. In contrast to the presumed separation between technical and managerial career tracks promoted in human resource management theory, researchers found that the great majority of engineers straddled both sets of responsibilities through a range of technical supervisory roles. One author used large-scale data sets to compare the aspirations and career decisions of recent engineering graduates [25], another analyzed the technical to managerial transitions of engineers working for a large manufacturing firm over twelve years [26], three surveyed engineers who followed a range of alternative paths such as project management, entrepreneurship, and hybrid options [1, 27, 28], and five examined the restricted career mobility of under-represented groups of engineers [2, 29-35].

Sheppard et al. studied the career aspirations and early career trajectories of engineering students in the United States using two large data sets [25], and found that graduates who reported the greatest confidence in their interpersonal and professional skills were more likely to have chosen non-engineering focused pathways, a troubling finding for those of us hoping to retain socially skilled engineers in the profession. Roberts and Biddle put a positive spin on this finding by pointing out that highly skilled technical engineers employed by an American manufacturing firm tended to become effective leaders after a year long adjustment period [26]. They arrived at this conclusion by analyzing the promotion patterns and performance appraisals of 2000 engineers employed by a large Midwestern manufacturing firm between 1978 and 1990 [26], putting to rest the widespread concern that promoting technically proficient engineers was a misallocation of human resources. In terms of career mobility, they observed the prevalence of rapid, semi-automatic promotion to the first supervisory position, followed by slower and more limited mobility after this point. The two most common career paths were: 1) technical analyst→ supervisor→ senior leader and 2) technical analyst→supervisor→ project manager. Job performance records suggest that engineers who struggled with supervision tended to move into project management rather than senior leadership roles. While Roberts and Biddle's study includes valuable insights about engineers' long-term career paths, they conducted it in a particular era at a single organization and thus their findings may not reflect the experiences of the engineering profession as a whole.

More recently, Tremblay and his colleagues surveyed 900 engineers in Quebec, Canada and found that their career paths were multiple and divergent, not homogenous or linear as might be expected by a dual (technical/managerial) career track model [28]. They identified five engineering career paths: technical, managerial, project-based, hybrid and entrepreneurial. Compared to engineers on the two traditional paths, they found that project managers and those on hybrid paths quickly reached a pay plateau, and entrepreneurs were most likely to view promotion practices in their respective organizations as unfair. This finding adds weight to Solymossy and Gross' hypothesis that engineers become entrepreneurs in order to capture the potential value of their intellectual property [27], a hypothesis based on their cross-sectional analysis of three cohorts of Canadian engineers who graduated in 1954, 1959 and 1964, surveyed once in 1965 and then again in 2009. The authors found that while most engineers began their careers in technical tracks, more than 50% of them ended up in management, with each successive cohort showing greater proclivity for entrepreneurship (21%, 24%, 30%). They argued that engineers who felt undervalued by organizational promotion patterns and pay structures sought out entrepreneurship because it maximized the return on their contributions. Related to the theme of feeling undervalued by organizational promotion patterns, Hodgson et al. conducted a pilot study on the engineering industry's recent move to "projectification" from the perspective of project managers in South West England and Scotland [1]. They found a gap between corporate messaging and the lived experiences of project managers. Corporate messaging involved the promise of upward mobility without compromising one's technical identity, while the experience of project managers in the study was one of limited authority, increased administrative responsibility, and a relative loss of technical status. Participants who had relinquished their positions as technical specialists in order to extend their professional reach were particularly troubled by the experience of being held accountable for situations they perceived to be beyond their control. Interestingly, while Hodgson and his colleagues frame the professionalization of project management as a relatively new phenomenon, Roberts' and Biddle's longitudinal study of engineering career paths in the 70s and 80s suggests that the role itself has been around for at least four decades as a viable career option for technically competent engineers who struggle with or express limited interest in management. These three studies suggest that while the dual career track assumption fails to reflect engineers' organizational realities, it does serve to privilege engineers on the two traditional career paths, providing them with a level of professional autonomy, upward mobility and decision-making authority rarely enjoyed by project managers, hybrid professionals, terminal middle managers and others on alternative career paths.

Finally, five of the articles we reviewed analyzed engineers' career paths in ways that accounted for at least one dimension of demographic diversity [2, 29-31, 36]. Adams surveyed 620 engineers in Ontario, Canada and found that those who were lower in the management hierarchy, internationally trained, female and/or racialized reported poorer working conditions than their white, male, Canadian educated, senior leader counterparts. Racialized engineers not only reported poorer working conditions but also experienced more difficulty finding work and balancing employer expectations with their ethical commitments. Marinelli and Lord examined the leadership transition experiences of 22 female, Australian engineering managers and found that most were on terminal career paths leading to middle rather than senior management: project engineer→ project manager; and discipline engineer→team leader [2]. Participants identified two barriers to promotion—limited access to sponsors who could open doors to senior management, and limited self-promotion among women when compared to male colleagues with similar seniority.

Compounding this "glass ceiling" problem faced by many female engineers, Cardador and her colleagues found that technical to managerial transitions rarely improved women's professional status or working conditions [30, 31]. Cardador and Hill surveyed 274 industry-based engineers from a diversity of engineering disciplines and firms in the Midwestern United States and found that female, but not male engineers on a managerial career path were at greater risk for professional attrition than their colleagues on other paths [31]. Their results are consistent with Foud's National Science Foundation study finding that 75% of women who left engineering were on a managerial path [36]. In a follow-up study, Cardador interviewed 35 female and 26 male engineers working in the same region and found that while many employers promoted women into management to signal diversity and inclusion, increasing female engineers' access to management had unintended consequences for the women she interviewed [30]. They felt less like real engineers, worked longer hours and had less flexibility than did their male and female counterparts in technical roles. In contrast to male colleagues in management roles, women were often streamed into middle management roles involving team co-ordination. Also, in contrast to more agentic notions of leadership in professions with large numbers of women [37], many male and female engineers participating in Carador's study characterized management in ways that were imbued with gender role stereotypes—being the "mom," organizing others, housekeeping and nurturing team members. Based on these findings, Cardador argued that disproportionately increasing female engineers' representation in managerial roles actually promotes the very sex stratification their employers are attempting to eliminate. At the centre of this dilemma is something she describes as the "inverted value hierarchy" in engineering—valuing technical over managerial roles, revering the former while viewing the latter as peripheral to or easier than core engineering work. To the extent that this inverted hierarchy shapes values held by a critical mass of engineers, it not only works against equity, but also against the professional leadership aspirations of all engineers.

The ten articles we reviewed in this section confirm the high incidence of technical to managerial role transitions within the engineering profession. More than half of them make another useful contribution to our understanding of engineering leadership by challenging the dual career track assumption that engineers either remain in specialized technical roles or transition to upwardly mobile management roles. Finally, by accounting for demographic diversity in relation to alternative career paths, five of the ten articles highlight structural barriers faced by women and other underrepresented groups when it comes to promotion, retention and working conditions. These findings suggest that CEOs and human resource professionals working in engineering-intensive organizations could support their firm's recruitment and retention efforts through two structural initiatives: 1) by conducting an organizational audit tracking who follows which path, the organizational accessibility and rewards associated with each path, and the barriers faced by under-represented groups of engineers, and 2) ensuring that engineers pursuing alternative (project management and hybrid) career paths have the resources and institutional authority necessary to meet their responsibilities. The career path researchers whose work we have reviewed make an important contribution to our understanding of the structural inequities faced by engineers in different roles, but their limited attention to individual engineers' strategies, perspectives and navigation techniques masks our ability to track their personal agency and leadership learning experiences. One way to explore the leadership learning experiences of all engineers is to examine their professional identity development process, something we do in the next section.

Theme 3: We are, we are, we are, we are, we are the engineers ♬

Nine of the articles we reviewed in our reading group foreground the professional identities of engineers who embrace, resist or partially adopt a leadership identity. The problem statement to which these authors respond is rooted in the strongly held perspective that engineering has always been and ought to remain a purely technical endeavour. Two authors illustrate the tension between engineers' professional identities and their organizational realities [38, 39], two help us explain and potentially bypass engineers' resistance to leadership [40, 41], one highlights the importance of engineers' identification as leaders [3], and the final four reveal gendered patterns in the availability of engineering identities [32-35]. A particularly interesting feature of these nine articles is their simultaneous attention to multiple units of analysis. That is, while engineers may experience their professional identities to be strongly personal, researchers who examine their identities in the aggregate detect professional, organizational and societal traces on their narratives about what it means to be an engineer.

Olesen conducted life history interviews with 17 engineers and 20 human service workers in Finland to explore the phenomenon of professional identity development as a learning process [39], and found that nearly all the engineers he interviewed viewed their own jobs as "not real engineering." His participants' widespread acceptance that "real engineering" was based on the application of specialized technical knowledge to practical problems made it difficult for them to accept and adapt to the sociotechnical realities of their work. The uniformity of these narratives suggests that an engineer's professional identity development is not a purely subjective or self-defined phenomenon. Clarke et al. demonstrate the impact of organizational factors on the professional identity narratives of 30 engineering managers employed by a large, recently downsized aerospace company [38]. As a group, participants shared similar yet internally contradictory accounts of this dramatic organizational event—merging dispassionate, rational, business-oriented explanations of their work with emotionally responsive facial expressions when discussing the friends and colleagues whose contracts had been terminated. Both of these studies demonstrate that engineers' identity-based narratives integrate professional aspirations, personal values, and organizational realities in coherent ways, even when these elements are seemingly incongruous. They also illustrate the considerable effort engineers put into preserving the technical purity of their identities in the face of complex organizational realities, with engineers in the first study referring to their work as "not real" engineering and those in the second using technical, rational narratives to characterize an emotionally turbulent organizational event.

One way to explain the durability of some engineers' technical identities in the face of socially complex organizational realities is to consider Gouldner's notion of a "cosmopolitan" professional orientation [40]. Gouldner studied the reference groups and organizational loyalties of academics at a small, private liberal arts college in the Midwestern United States and coined the term "cosmopolitan" to characterize the professional orientations of professors who viewed themselves as technical specialists. These participants measured themselves against an external reference group of similarly trained academics in their discipline, and tended to express limited loyalty to the college. In contrast, professors with a "local" orientation viewed themselves as contributing members of the "Co-op College" faculty. They were aware of their disciplinary training, but tended to measure themselves against a reference group of colleagues and view themselves as primarily responsible to their students and employers. To the extent that these orientations can be applied to engineers, we believe those with a cosmopolitan orientation will hold on tight to their technical identities resisting organizationally-specific administrative roles that take them away from purely technical work; while those with a local orientation would be more likely to embrace a heterogeneous engineering leadership identity without feeling like they are losing a fundamental part of themselves. Remaining on the theme of resistance, Rottmann et al. conducted focus groups and interviews with 73 engineers employed by four engineering-intensive organizations in South-central Canada and found that the vast majority of participants resisted the idea of engineering leadership until it was framed as a professionally-relevant form of influence.[41] When leadership was re-defined in a way that honoured both technical and social elements of the profession, however, many participants embraced one of three compound leadership identities. That is, once participants saw that mentoring co-workers, facilitating team dynamics, and driving organizational innovation did not require them to abandon their technical identities, many participants accepted the notion of leadership. Applying these findings to

Gouldner's framework, we believe engineers can learn to embrace both cosmopolitan and local orientations by simultaneously identifying with two communities—an external network of professional engineers and the communities of practice within their organizations. So long as they learn to view these orientations as complementary rather than mutually exclusive, they can come to embrace a leadership identity without feeling like they must relinquish their technical foundations. Engineers who feel a sense of belonging, not only to their professions, but also to their organizations might then be more likely to embrace leadership responsibilities in professionally-meaningful ways.

Accepting a compound socio-technical identity is not simply about feeling comfortable in one's skin as an engineering leader. It is also, fundamentally, about learning how to be one. Until engineers accept that their profession legitimately involves both technical and social elements, and that learning how to grasp both domains is cognitively challenging work, they will have a hard time adapting to their leadership and management responsibilities. Racine studied the social identity development processes of 20 engineers and scientists in unit manager roles at several technical organizations in the Midwestern United States and found that those with technical acumen who were promoted to management without understanding the social complexity of the situation often struggled with their jobs [3]. Those who eventually went on to become successful leaders recognized that supervision was challenging work, that interpersonal challenges provided them with important learning opportunities, and that there was inherent value in both social and technical aspects of engineering practice. This notion of accepting the heterogeneous, socio-technical nature of engineering is not only useful to individual engineers making a technical to managerial transition. It also has the potential to contribute to organizational diversity and inclusion efforts by disrupting dualistic thinking at the heart of many discriminatory workplace practices. Faulkner's ethnographic study of five engineering workplaces—two English oilfields, two Scottish construction companies and one US-based software company [32-34], illustrates this point by examining the impact of dualistic thinking on organizational inclusion. Among other penetrating insights, she argues that characterizing engineering as technical (not social), hard (not soft), function (not form), design (not management), and implicitly male (not female), makes it difficult for all engineers—especially women and gender non-conforming men—to integrate their "nuts and bolts" identities with the heterogeneous nature of their work. While the great majority of male and female engineers identify as technical rather than relational specialists, sex-role stereotypes about the gendered nature of technical and social work create subtle organizational dynamics that make it easier for male than female engineers to belong. Most directly related to leadership, Faulkner observed that these subtle discriminatory practices made it difficult for women as well as racialized and gender non-conforming men to achieve the level of belonging necessary to shape the organizational culture of their respective workplaces. This was as true in the US-based software company with an explicit employment equity policy as it was in the UK-based oilfields where sexist jokes and pub language were a conversational norm.

Another powerful barrier to equity, inclusion and belonging in engineering workplaces, involves the limited number of professional identity options open to female engineers in comparison to their male counterparts [34, 35, 42, 43]. Kvande and Rasmussen studied male-female dyads in six Norwegian organizations and found that their participants' workplaces were differently gendered in ways that produced a diversity of acceptable masculinities—"cavaliers," "father's sons," "competitors," "comrades," and "comets"—all of which constrained female engineers' opportunities for career development [35]. Women, in contrast, were only visible when they fit the "challenger" profile—daughters of engineers who occupied management roles, had families, and had achieved a level of work-life balance with which they were comfortable. In other words, the only group of women whose engineering identities were accommodated in both organizational types—"static hierarchies" and "dynamic networks"—had already achieved a state of equilibrium after successfully swimming against the grain. Faulkner and Tonso similarly point to the large number of engineering identities in workplace and university contexts that accommodate male engineers while remaining largely inaccessible to their female colleagues and peers [34, 42, 43].

The nine articles we have reviewed in this section demonstrate that engineers' professional identity development processes involve a fusion of personal, professional and organizational influences requiring individuals to grapple with and integrate seemingly incongruous elements of their professional practice. Based on these findings engineering professors can facilitate students' leadership learning processes by integrating social issues into the core technical curriculum; engineering leadership researchers can examine how specific engineers grapple with their professional identities as they encounter organizational realities that contrast with their expectations; human resource professionals can observe the demographic make up of informal social groupings at their respective organizations to identify potential barriers to inclusion; and engineers' professional and disciplinary society leaders can mount a professional relations campaign that frames engineering as a historically socio-technical profession. As a whole, these studies are significant to the engineering leadership literature because they explain why engineers with strong technical orientations who occupy management roles at fairly high rates, nevertheless resist identifying as leaders. Unfortunately, while this body of literature includes some very useful insights, it is written in a densely theoretical way, potentially limiting the uptake of study findings by the very audiences in a position to do something about them.

Summary of findings

The three bodies of literature we reviewed as a group complement one another by examining engineering leadership from three different perspectives. Please see table 3 for a summary of our findings. Authors contributing to each theme make unique contributions to the theory and practice of engineering leadership by framing their studies in distinct ways, foregrounding particular levels of analysis, using similar methodological strategies to substantiate their claims, and gearing their findings to audiences who define the problem in similar ways. Unfortunately, all three groups of researchers fail to address how engineers actually learn to lead in their respective workplaces. In the next section, we prepare ourselves to fill this gap by reading the three themes through situated learning theory.

Table 3: Three key themes in the engineering leadership literature

Theme	**Leadership effectiveness: Skills, traits and styles**	**Engineers' career paths and transitions**	**Professional identity development**
Problem Statement	The competitive global economic context is leaving engineers with exclusively technical skills behind.	The traditional idea of dual track engineering careers contrasts with engineers' more hybrid workplace	The deeply internalized notion of technical purity makes it difficult for many engineers to accept socially demanding workplace realities.

		realities.	
Main argument (s)	Engineers must develop professional, communication and interpersonal skills to complement their technical training.	We must make space for engineers' multiple, divergent career paths—technical, managerial, project management, entrepreneurial & hybrid.	Unless engineers recognize the socio-technical nature of their field, it will be difficult for them to think of themselves as leaders and accept their professional responsibilities.
Data sources	-Industry Surveys -Experimental design -Reflections on experience	-Longitudinal surveys -Interviews with engineers undergoing career transitions -Analysis of human resource records	-Organizational ethnographies -Surveys -Job shadowing -Interviews
Unit of analysis (foregrounded)	Individual	Organizational	Professional (with deliberate attention to personal, organizational and societal levels of analysis)
Intended Audience (primary)	-Engineering educators & corporate trainers	-HR professionals	-Researchers (sociology of the professions; science & technology studies)
So what?	Engineering educators and corporate trainers must integrate the instruction and identification of social skills into otherwise technical learning opportunities. Pay attention to which engineering leadership styles are ascribed to, derived from, and effective for whom.	Find ways to support engineers making career transitions. Support diverse recruitment and retention efforts by ensuring that engineers on alternative career paths have the authority to meet their responsibilities. Examine who follows which path, the organizational accessibility of each path, and barriers faced by under-represented groups of engineers.	Disrupt social/technical dualisms by integrating social issues into the technical curriculum. Examine how engineers grapple with their professional identities as they encounter organizational realities that contrast with their expectations. Compare the range and types of engineering identities available to privileged and under-represented groups.
Significance	Promotes the idea that all engineers can learn to lead.	Longitudinal studies produce important insights about engineers' actual career trajectories.	Identifies a root cause of many engineers' resistance to developing a leadership identity.
Limitations	Limited attention to social and organizational context. What kinds of leadership skills, traits and styles are effective for whom in what contexts? Eg. When demographically over and underrepresented engineers demonstrate assertiveness in American offshore drilling companies, do colleagues appreciate it equally?	Limited attention to individual agency. Certain career tracks may be prominent in engineering organizations, but how do specific individuals decide which path to pursue? What do they learn from their experiences?	The intended audience has limited interaction with those in a position to do something about the findings. Also, those in a position to apply the findings may not find the theoretically dense writing accessible or relevant.
Who's choice?	Doug, Qin, Cindy	Alison, Maddy, Cindy	Mike, Serhiy, Cindy
Key Authors	Farr, Hartmann, Lappalainen	Tremblay, Robert & Biddle, Cardador	Faulkner, Racine, Clarke

Discussion: Reading our findings through four conceptual tensions

Literature reviews allow researchers to build on rather than replicate the foundational work of others in their field. They allow us to learn from relevant bodies of research and make unique, meaningful contributions to a shared topic of inquiry. Our multi-disciplinary reading group may have led us in multiple directions, but it also provided us with a mechanism for inter-rater reliability. When a single reviewer identifies a gap in the literature, it may be the result of a personal blind spot, but when seven readers socialized in different disciplines search for a particular line of analysis and come up short, it is most likely because there is limited research on the target domain. Our community of researchers identified a clear gap in the engineering leadership literature—the paucity of studies examining engineers' leadership learning processes in industry contexts. While we reviewed two articles on undergraduate students' leadership learning experiences [5, 44] and two articles highlighting the isolated experiences of engineers attempting to apply university-based management lessons to their work [45, 46] none of the papers we reviewed examined engineers' leadership learning processes in their respective workplace contexts. Our discussion draws connections between our phenomenon of interest and literature review findings by situating each body of literature along four conceptual tensions relevant to engineering leadership learning—leadership as a position/process, social action shaped by human agency/social structure, learning as a situated/formal experience, and social justice as a constitutive/peripheral concern. Please see Table 4 for a summary of our analysis.

Table 4: Reading the engineering leadership literature through four conceptual tensions

Theoretical source of conceptual tension	**Skills, traits and styles of effective engineering leaders**	**Engineers' career paths and transitions**	**Engineers' professional identity development**
Leadership theory	Process	Position	Position/Process
Social action theory	Agency	Structure	Structure/Agency
Learning theory	Formal	Situated	Situated
Social justice theory	Depends on author	Depends on author	Depends on author

Tension 1: Leadership as a position/process

Komives and her colleagues generated a leadership identity development model comparing two distinct ways of understanding leadership—leadership as a position and leadership as a process [5]. The first restricts leadership to individuals in supervisory or managerial positions, while the second characterizes leadership as a phenomenon that can be embodied and mobilized by all of us, regardless of our respective organizational locations. While the authors did not focus on engineers, their model allows us to detect distinct conceptions of leadership imbedded in the literature we reviewed. Looking across the three bodies of literature, we found evidence that researchers characterize leadership as both a position and a process—with the effective leadership scholars falling on the process end of the continuum, the career path researchers falling on the position end, and the professional identity researchers blending the two. What are the implications of this grouping for our study on engineers' leadership learning? By framing leadership as a process, we can sample broadly, maximizing the applicability of our findings to engineers across organizational locations. In contrast, by framing leadership as a position, we facilitate cross case comparisons of engineers in similar roles at different organizations. By framing engineering leadership as both a process and a position, we can ask contextually specific questions about the technical to managerial transitions of engineers in formal management roles without discounting the leadership learning experiences of those on non-managerial paths.

Tension 2: Social action shaped by human agency/social structure

Two articles we read as a group helped us characterize leadership learning as a practice of organizationally contextualized action [7, 8]. Archer's theory of human agency foregrounds the aspirations, strategies and social projects of individuals in pursuit of personally meaningful goals, while Billett's study of workplace affordances highlights the role of organizational policies, practices and norms impinging on the feasibility of these goals. This conceptual tension between human agency and social structure drives our second analytic read of the literature. Mapping closely onto our leadership as position/process continuum above, effective engineering researchers tended to frame individual engineers as minimally restrained social actors, thereby standing on the human agency end of the continuum, while career path researchers highlighted the impact of organizational structures and practices on engineers' career mobility—thereby standing on the social structure end of the continuum. Professional identity researchers tended to engage with the agency/structure dynamic as an inseparable tension. What are the implications of this grouping for our study exploring how engineers learn to lead in industry contexts? At the human agency end, it suggests that we examine the relationship between individual engineers' career aspirations and their decisions about which leadership learning experiences to engage in. At the social structure end, it suggests that we analyze leadership learning opportunities in the aggregate to learn how engineering intensive workplaces facilitate and constrain the leadership learning opportunities of engineers across organizational and social locations. Interestingly, our first two conceptual tensions produced a similar spread in our three engineering leadership themes. Specifically, bodies of literature framing leadership as position tended to privilege social structure and bodies of literature framing leadership as a process tended to privilege human agency. This conceptual overlap suggests that we should either eliminate one conceptual tension from our framework, or use our findings to build inter-disciplinary bridges between sociologists who speak in terms of structure/agency, and leadership theorists who frame authority in positional/process-based terms.

Tension 3: Situated and formal learning opportunities

Lave and Wenger's foundational text on situated learning theory and Johri and Olds' article advocating for the integration of situated learning theory into engineering education research inform our third conceptual tension—learning as a situated or formal endeavour. Briefly, situated learning stems from engineers' day–to-day participation in communities of professional practice, while formal learning is often delivered in a more intentional, didactic manner through classes, workshops and seminars. Authors of the effective engineering leadership skills, styles and traits literature urged engineering educators to integrate leadership skill activities into the curriculum, thereby privileging formal learning. In contrast, the engineering career path researchers' "give them a year to figure it out" motto, and the professional identity researchers' attention to the powerful socializing forces underpinning engineers' identity formation processes suggests that the second and third bodies of literature we reviewed privilege situated learning. What are the implications of this grouping for our research? Given our focus on leadership learning in industry rather than university contexts, it makes sense for us to foreground situated learning processes in our study. This type of deeply contextualized learning is highly valued by many professionals, including engineers because of its timely, relevant and practical nature. Exclusive attention to situated learning does, however, have its drawbacks. Chief among them is the potential reproduction of problematic practices that have taken root in an organization or profession—including the durability of dualistic thinking about the technical (not social) nature of true engineering practice. One way to introduce critical thinking into our study is to invite participants to discuss catalytic events—including formal learning opportunities—that have transformed their thinking about how leadership learning works in their particular organizational contexts. Ultimately, it would serve us well to explore how and when engineers learn to lead, the pitfalls they face as they progress through their careers, and the range of experiences, including formal educational opportunities, that catalyze their learning.

Tension 4: Social Justice—Hey! What about us?

Eleven of the thirty-two authors whose articles we reviewed placed equity, diversity or inclusion at the centre of their engineering leadership research. Interestingly, these articles broke down in ways that loosely paralleled our three themes— effective engineering skills, traits and styles; engineering leadership career trajectories; and engineers' professional identity development. For this final layer of analysis we use the social justice insights drawn from these eleven articles to examine gaps in the remaining twenty-one. The availability of at least two equity-oriented articles in each thematic group allowed us to follow Pawley's "diversity as default" recommendation—that is, to account for diversity even when it is not the primary phenomenon under investigation [49]. For the effective engineering leadership research this means acknowledging the unconscious biases implicit in our notions of leadership effectiveness. For the engineering career path research, it means tracking differences in status, rank, working conditions and promotion across diverse demographic groups of engineers. Finally, for the professional identity development research, it means disrupting dualistic thinking and examining who is accommodated by the widest range of agentic professional engineering identities. Across all three bodies of literature, it behoves us to characterize engineers as a diverse rather than homogenous group, honour the intersectional nature of engineers' social identities, recognize the historically heterogeneous nature of engineers' work, deliberately diversify our sample, and avoid generalizing findings from existing research based on the experiences, perspectives and prescriptions of a privileged demographic group to the population of engineers as a whole.

Significance & limitations of reviewing the literature CoP style

Our community of seven interdisciplinary readers—three engineers, three social science researchers and one engineering student—identified and collectively reviewed thirty-two articles on engineering leadership and several additional articles on situated learning theory to gain a foundational understanding of engineers' leadership learning in industry contexts. In contrast to traditional literature reviews that are completed as a solitary endeavour following a single line of inquiry, our team generated collective search criteria each week, and then set out on seven divergent paths related to personal, epistemological and methodological commitments. For example, a senior engineering professor who founded a leadership institute based on the notion that engineers can and should learn to lead chose several articles examining the skills and traits of effective engineering leaders, while a staff member who was completing a master's thesis on professional engineering accreditation practices selected several articles on engineers' professional identity development processes. All seven members, to a greater or lesser extent, interpreted collective search criteria in ways that aligned with our personal interests, thereby introducing methodological, conceptual and issue-related diversity into our community of readers. An important benefit of this process was the enriched experience we had as reading group members. Unfortunately, a corresponding disadvantage was the challenge we faced when attempting to write a coherent narrative. To tighten our literature review, we separated the five original themes into three content-based themes and a series of conceptual lenses. Interestingly, the engineers on our team selected slightly more than half of the articles that made up our three content-based themes, while the social scientists on our team selected nine of the eleven articles that made up our conceptual framework. Thus, to make a crude distinction, the "value add" of having engineers on the team was connected to their professional leadership experiences and professionally relevant article selections, while the "value add" of having social science researchers on the team was connected to our interpretive, theoretical framing, and synthesis of key research findings.

Recommendations for engineering educators, industry leaders & researchers

The process of analyzing three bodies of engineering leadership literature through a conceptual framework rooted in leadership learning theory enabled us to generate a tentative list of recommendations for engineering educators, industry leaders and engineering leadership researchers interested in scaffolding engineers' leadership learning experiences. We conclude our paper by identifying these theoretically and empirically derived lessons.

Engineering educators:

- Integrate social issues into the core technical curriculum.
- Use case studies to illustrate the complementary rather than mutually exclusive nature of social and technical spheres of engineering leadership practice.
- Use challenging design projects to help students understand that learning how to integrate social and technical domains of engineering practice is cognitively challenging work.
- Generate assignments that encourage students to experiment with the skills, traits and styles associated with effective engineering leaders as a way of advancing personally meaningful goals.
- Critically analyze and discuss which engineering leadership styles, traits and skill sets are ascribed to and effective for whom.
- Use critical incident reflections and case studies to analyze prominent socialization patterns in engineering education and workplace contexts. This would be particularly meaningful for students who have recently returned from their co-op or internship placements.

Leadership trainers in industry:

- Identify organizationally specific learning catalysts and pitfalls related to leadership then scaffold these situated learning opportunities in a timely manner.
- Design and facilitate widely accessible, organizationally contextualized leadership learning opportunities.

Industry leaders & human resource professionals:

- Conduct/sponsor an organizational audit tracking who follows which career path, the organizational accessibility and rewards associated with each path, and the barriers faced by under-represented groups of engineers.
- Improve leadership mobility (in hierarchical organizations) and influence/pay equity (in flatter organizations) by inviting employees with middle management responsibilities to anonymously raise structural barriers to inclusion.
- Increase the influence of engineers in project management and team leadership roles by ensuring they: 1) have the necessary resources and institutional authority to meet their organizational responsibilities, and 2) have opportunities to integrate both technical and social competencies into their work.
- Foster a sense of organizational belonging and commitment among technically oriented engineers to help them embrace their leadership responsibilities.
- Support diverse recruitment and retention efforts by ensuring that under-represented engineers do not shoulder the weight of "inverted hierarchy" [30] (technical > middle management) career paths.

Engineers' professional association leaders

- Mount a professional relations campaign that frames engineering as a historically socio-technical profession.
- Highlight the personal, organizational and societal impact of demographically diverse engineering leaders.

Researchers:

- Conduct empirical research examining how engineers learn to lead in a range of industry contexts.
- Track differences in status, rank, working conditions and promotion across demographically diverse groups of engineers, making sure to flesh out each path with a series of stories honouring the intersectional nature of engineers' identities.
- Avoid attributing the perspectives and prescriptions of a privileged demographic group of engineers to the population of engineers as a whole.
- Examine how engineers grapple with their professional identities as they encounter organizational realities that contrast with their expectations.
- Compare the range and types of engineering identities available to privileged and under-represented groups.

Conclusions and next steps

The forty-three articles we reviewed in our interdisciplinary reading group broke down into three distinct themes—the skills, traits and styles of effective engineering leaders, engineering leadership career paths, and engineers' professional identities—as well as four conceptual tensions—leadership as a position/process, social action shaped by human agency/social structure, learning as a situated/formal process, and social justice as a peripheral/constitutive concern. While many of these articles concluded with recommendations for engineering educators and industry leaders, none of them examined how engineers actually learn to lead in their respective workplace contexts. The effective engineering leadership literature examined what engineers ought to learn from the perspectives of industry leaders, without addressing how or what they actually learned. The engineering career path research examined the varied leadership trajectories engineers pursue and the resource implications tied to each path, without examining what engineers on different paths learned from these organizationally situated experiences. The professional identity research explored the impact of deeply held notions of technical purity on engineers' leadership identity formation processes, without exploring what engineers who eventually came to see themselves as leaders learned from the process. Finally, the theoretical texts we reviewed provide us with important conceptual ties to leadership learning in workplace contexts, without examining the particular leadership learning experiences of engineers. The next phase of our engineering leadership project addresses this gap by examining how senior engineers learned to lead in a range of industry contexts. Our research team is well positioned to fill this gap by bridging two disciplines: engineering leadership and workplace learning. The engineering leadership educators on our team bring important professional insights to the conversation, while the social science researchers bring a deep understanding of workplace learning theory. Together, we have the necessary expertise to challenge our assumptions and examine what engineers mean when they say, "I learned to lead by leading." To the extent that we do this in a way that addresses the full diversity of engineers' leadership aspirations, career paths, disciplinary backgrounds, organizational locations and intersectional identities, we will be contributing, alongside industry leaders, human resource professionals, professional association leaders, and engineering educators to a more just and robust body of engineering leadership knowledge and practice.

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