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The Ebb and Flow of Engineering Leadership Orientations

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The Ebb and Flow of Engineering Leadership Orientations

Context

The National Academy of Engineering and Engineers Canada have been advocating for engineers to assume greater leadership responsibilities in their workplaces and in society [1, 2], but little is known about how engineers orient themselves toward leadership. A growing body of literature on engineering leadership includes: 1) calls for leadership and professional skill development in faculties of engineering [1-15]; 2) engineering leadership program descriptions written by institutional insiders [16-30]; and 3) applications of traditional leadership theory to engineers' work [31-40]. While this literature presents us with important insights about the rationale for including leadership education in engineering programs, descriptions of the content and pedagogy used by instructors and faculty members beginning to implement these programs, and assessments of engineers' work in relation to managerial leadership theories, very few researchers have stepped back to conceptualize engineering leadership from the perspective of professional engineers. In phase one of our study we attempted to fill this gap by exploring how engineers working in industry thought about leadership, how they characterized leadership exemplars in their profession and how they oriented themselves to professionally relevant conceptions of leadership [41, 42]. After learning that the engineers in our sample overwhelmingly resisted the idea of leadership, we returned to the literature in search of engineering leadership theory, but could only find empirical studies evaluating engineers against leadership frameworks borrowed from the management and psychology literature [6, 31-33, 37-40, 43-46]. Our concern that standards borrowed from other disciplines were among the causes of engineers' resistance to the idea of leadership led us to develop a theory of leadership grounded [47] in the experiences of 45 engineers employed by four Canadian engineering intensive organizations. Through an iterative analytic process, we identified three professionally relevant leadership orientations— *Technical Mastery* (the "go to" engineer for technical questions), *Collaborative Optimization* (engineers who build high performing teams) and *Organizational Innovation* (engineers whose creative ideas drive the company) [41, 42]. Since our preliminary theory was based on the experiences of a small sample of engineers, we developed a survey to test the wider professional resonance of the orientations.

In this paper we report on phase two of the study, a quantitative analysis of the three engineering leadership orientations. In particular, we respond to the following six questions:
1) What is the prevalence of particular engineering leadership orientations across the sample?
2) How do engineers' leadership orientations differ by sex, experience and leadership role?
3) How do engineers' leadership orientations change across their career trajectories?
4) How do engineers' leadership orientations change in response to different situations?
5) When do engineers begin to value the skills associated with each orientation?
6) What are the skills and traits associated with exemplary engineering leaders of each orientation?

Methodology

The primary source of data for our analysis was a survey of 175 engineers working for two international engineering-intensive organizations with head offices in Canada. We sent the survey link to key leadership personnel at our two partner organizations and invited them to distribute it to their engineers. Our contact at the smaller organization distributed the survey to all engineers working across provincial locations, while our contact at the larger organization distributed it to a sample of (primarily junior) engineers working at the central office. According to our records, 288 employees opened the survey and 175 completed at least the first four sections.

Please see table 1 for sample survey questions. Part one of the survey solicited background information about the age, sex, discipline, department and leadership roles held by individual participants. Parts two to four asked participants to respond to Likert style questions about their technical, collaborative and strategic planning tendencies across time (student, junior engineer, senior engineer) and situations (task, team, aspiration/satisfaction). Parts five through seven of the survey invited individuals to identify and evaluate the skills and traits of three colleagues in their organization who exemplified each of the three leadership orientations—technical mastery, collaborative optimization and organizational innovation. We derived our list of skills from the twelve graduate attributes named by the Canadian Engineering Accreditation Board (similar to ABET) [48, 49], and the core engineering competencies against which internationally trained engineers are evaluated, as defined by Engineers Canada [50]. We were less systematic about our trait selection. The research team generated 20 traits we believed to be characteristic of strong leaders and strong engineers.

TABLE 1: SAMPLE SURVEY QUESTIONS

Survey section	Sample Question	Focus	Code
Part 1: Demographics	Age: 20-29; 30-39; 40-49; 50-59; 60+	Self	Demographics (Age Category)
Part 2: Student experiences	As a student, when dreaming about my future, I imagined doing technically complex work. *(1 never, 2 rarely, 3 occasionally, 4 frequently, 5 always)*	Self	Time (student) Situation (aspiration/satisfaction) Orientation (TM)
Part 3: Junior Engineer	When beginning to work with a new team, I establish strong working relationships with team members *(1 never, 2 rarely, 3 occasionally, 4 frequently, 5 always)*	Self	Time (junior engineer) Situation (team) Orientation (CO)
Part 4: Workplace now	When beginning a new project, I focus on organizational goals. *(1 never, 2 rarely, 3 occasionally, 4 frequently, 5 always)*	Self	Time (workplace now) Situation (task) Orientations (OI)
Part 5: selecting leadership exemplars	Imagine a person who builds high performing teams by bringing out the best in everyone: **Pseudonym**:________________ **Sex**: Male Female	Engineering exemplar (admired colleague)	Orientation (CO) Demographics (sex)
Part 6: Engineering skills of exemplary leaders	Solves problems using appropriate engineering principles: OI exemplar (chosen pseudonym pops up) *(1 poor………………………………..…5 exemplary)*	Engineering exemplar	Skill type (A: applying engineering knowledge) Orientation (OI)
Part 7: traits of exemplary leaders	Choose up to five traits that best describe each of your exemplary leaders: TM exemplar (chosen pseudonym pops up)	Engineering exemplar	Trait type (22 choices listed) Orientation (TM)

Sample Demographics

Our sample is slightly younger and less experienced than engineers in the country with a slight over-representation of chemical and mechanical engineers. The gender split reflects that of Canadian engineering graduates over the past two decades. Please see Table 2 below for a summary of our demographic data.

TABLE 2: SAMPLE CHARACTERISTICS

Category	Sub-Categories	% of Sample
Sex	Male	74
	Female	26
Age	20-29	43
	30-39	33
	40-49	10
	50-59	10
	60+	4
Engineering Experience (years)	0-2	22
	3-5	24
	6-10	25
	11-20	11
	21-30	10
	31-44	8
Leadership Roles	Engineer in Training	21
	Engineer, not management	31
	Middle management	35
	CEOs/Directors/Executives	13
Discipline	Chemical	30
	Mechanical	28
	Electrical	10
	Materials	7
	Other Engineers	12

Survey Reliability & Validity

Prior to presenting our findings, it behoves us to demonstrate that the 31 items contributing to our three leadership orientation scales hold together sufficiently well to be arithmetically manipulated. We used Cronbach's alpha to test the reliability of survey scales using the full complement of data collected (n=175) and found that all three scales met the social science reliability threshold of 0.7 [51]. The validation of survey scales—particularly using construct or criterion validity—is more difficult to assess since the concept of "engineering leadership" has not yet been adequately theorized in the literature. Fortunately, however, it was possible for us to assess the face validity of our survey by presenting small test groups from both organizations with survey results about their primary leadership orientations. The fact that engineers who had resisted the idea of leadership did not resist the three leadership orientations, and that members of the test groups experienced their survey results as consonant with their professional identities provided us with a preliminary measure of validity for our survey.

Methodological limitations

Our first methodological limitation emerged from our decision to use a convenience sample [52]. While this sampling strategy allowed us to pilot the survey in an efficient manner with supportive industry partners, it prevents us from generalizing our findings to the full population of North American engineers. Our second methodological limitation was a consequence of our small sample size. We had initially planned to use inferential statistics to analyze our data, but the data points feeding into our scales failed to meet the assumptions of normality and heterogeneity of variance underlying these tests. Thus we could not legitimately conduct parametric tests such as t-tests or analyses of variance. We ran a few non-parametric tests on our data, however with the limited power of these tests, only one finding achieved statistical significance—the over-representation of men in participants' identification of exemplary leaders. Since this finding emerged from a secondary analysis of our data and stands outside the parameters of our initial research program we examine it in another ASEE paper [53]. In this paper, we use descriptive statistics to investigate research questions for which our survey was initially designed—engineers' leadership orientations across demographic, situational and temporal markers.

Findings

Our findings provide descriptive, organizationally bound responses to the six research questions identified in our introductory section.

1) **What is the prevalence of the three engineering leadership orientations—technical mastery (TM), collaborative optimization (CO) and organizational innovation (OI)—across our sample?**

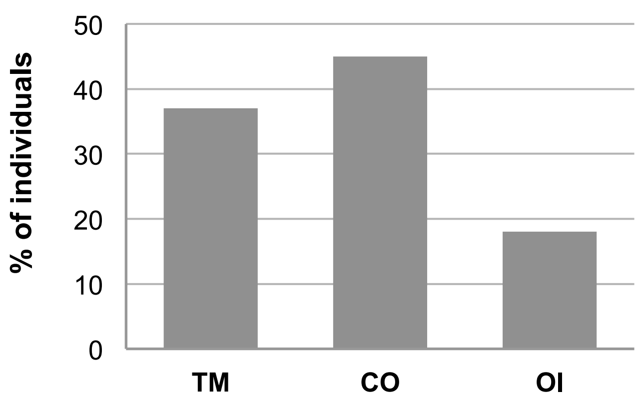

FIGURE 1: LEADERSHIP ORIENTATION PREVALENCE

Overall, as might be expected in a highly technical, collaborative profession that resists traditional notions of leadership, a greater proportion of engineers in our sample prioritized collaborative optimization (45%) and technical mastery (37%) over organizational innovation (18%). Please see Figure 1 for an illustration of these results. The fact that our sample was younger and less experienced than the Canadian engineering workforce as a whole might have contributed to this finding, as novice engineers are less likely to participate in strategic planning opportunities with organizational influence early in their careers.

2) How do engineers' leadership orientations differ by sex, experience and leadership role?

As illustrated in Figure 2 below, men were equally likely to prioritize technical mastery (40%) and collaborative optimization (39%), while women were more likely to prioritize collaborative optimization (62%) over technical mastery (30%). Engineers of both sexes accorded organizational innovation the lowest priority of the three orientations, but men were more likely than women to prioritize it (21% vs. 8%).

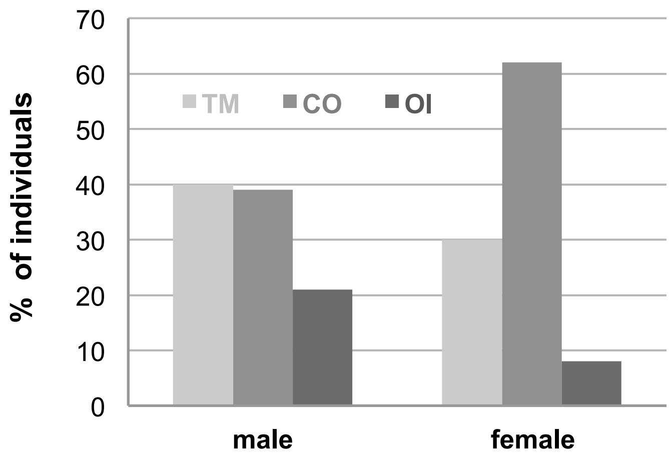

FIGURE 2: LEADERSHIP ORIENTATION BY SEX

Since age and years experience were highly correlated, we chose to focus on one. Please see Figure 3 for an illustration of engineers' preferred leadership orientations by experience.

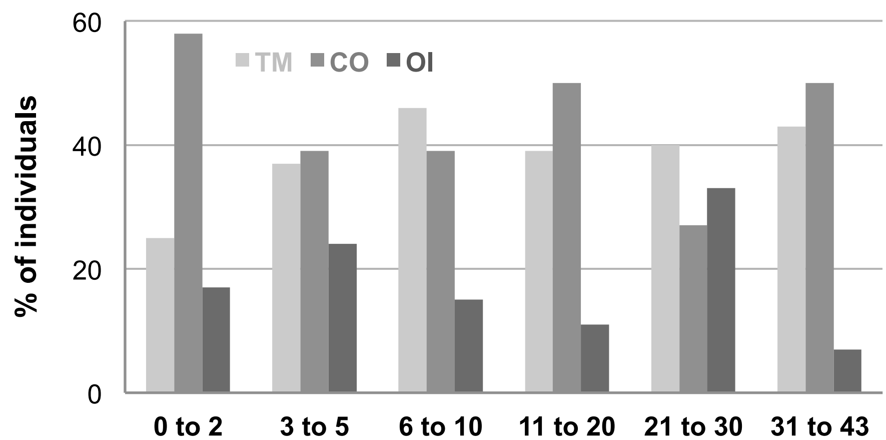

FIGURE 3: LEADERSHIP ORIENTATION BY YEARS EXPERIENCE

No clear patterns emerge from this graph with the exception of a strong orientation among novice engineers (zero to two years) toward collaborative optimization. This "experience" effect may be confounded by a "sex" effect, as women make up a greater percentage of individuals in their first two years (35%) than in the sample as a whole (26%).

Finally, we found no clear pattern of leadership orientation preferences by organizational position. Please see Figure 4 for an illustration of these findings. While we expected engineers with formalized management responsibilities to prioritize organizational innovation over the other two orientations, this did not pan out at the top of the hierarchy. If any group of individuals prioritized organizational innovation to a greater extent than the sample as a whole, it was engineers in middle management positions.

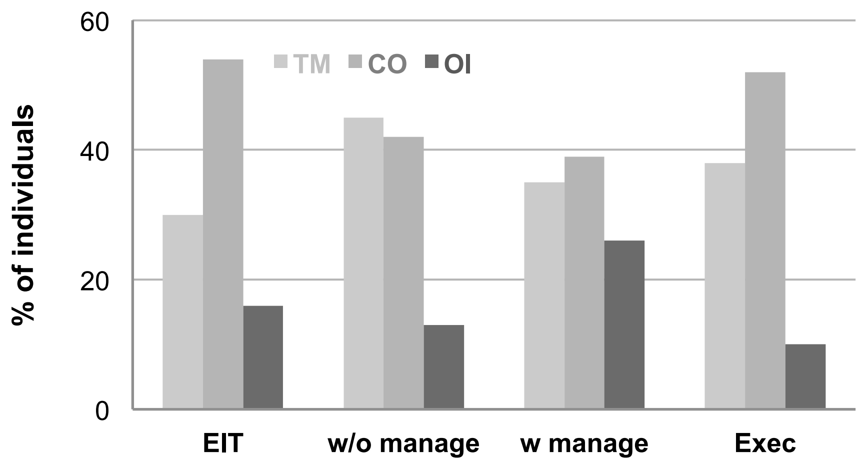

FIGURE 4: LEADERSHIP ORIENTATION BY ROLE

Looking across the three demographic categories of sex, years experience and organizational position, we observed a slight prioritization of collaborative optimization among women and engineers in their first two years at work. Future studies with a larger sample of engineers should further investigate the relationship between sex, experience and leadership orientation.

3) **How do engineers' leadership orientations change across their career trajectories?**

Up to this point, we have compared individuals with different demographic and organizational characteristics to one another at a single point in time. For question three, we compare individuals to themselves across time. In order to do this meaningfully, we have omitted data from individuals in their first five years who lacked three distinct temporal data points. When we analyzed the data by developmental stage, we found that as engineers with at least six years experience progressed through their careers from students to junior engineers to senior engineers, the percentage who prioritized technical mastery dropped (69% to 28%), while the percentage who prioritized collaborative optimization (20% to 43%) and organizational innovation (11% to 29%) rose. A key limitation of this finding is our use of a cross sectional data collection instrument paired with participants' memories to access longitudinal data points, however, methodological limitations aside, figure 5 below indicates that the intermediate and senior engineers in our sample who reflected on their student and junior engineering years tended to rely more heavily on collaboration and system planning later in their careers than they had as students or young professionals. This pattern suggests that engineering leadership orientations are malleable across an individual's developmental trajectory.

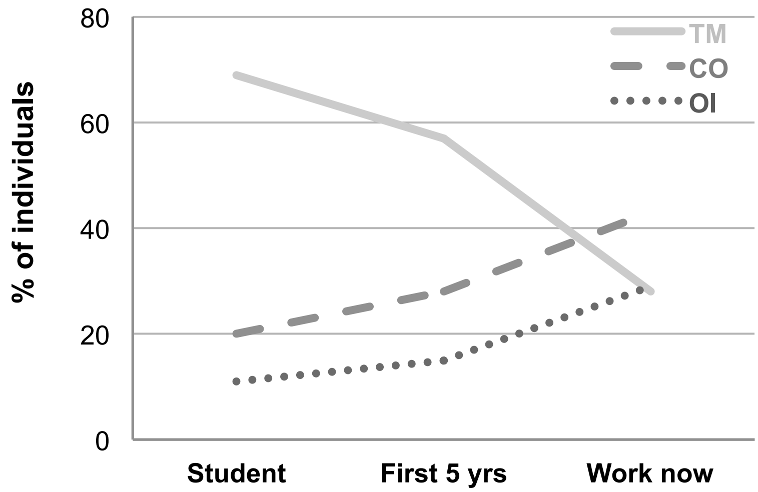

Figure 5: Leadership Orientation by Career Trajectory

4) **How do engineers' leadership orientations change across situations?**

Beyond the interesting developmental trend illustrated by Figure 5, we found that situational prompts also shaped engineers' identification with the three leadership orientations—tasks, teamwork and job satisfaction (or "aspirations" in the case of students). Please see table 1 in our methodology section for sample survey questions representing each situational prompt. Figure 6 below illustrates engineers' leadership orientations by situation. Engineers at all career stages were most likely to prioritize technical mastery when provided with task-oriented prompts (64%) and collaborative optimization when provided with job satisfaction (45%) and teamwork (48%) prompts. Job satisfaction was the most likely of three situations to elicit strong identification with organizational innovation. These findings suggest that engineering leadership orientations are malleable—not only over time, as indicated by Figure 5, but also across situations.

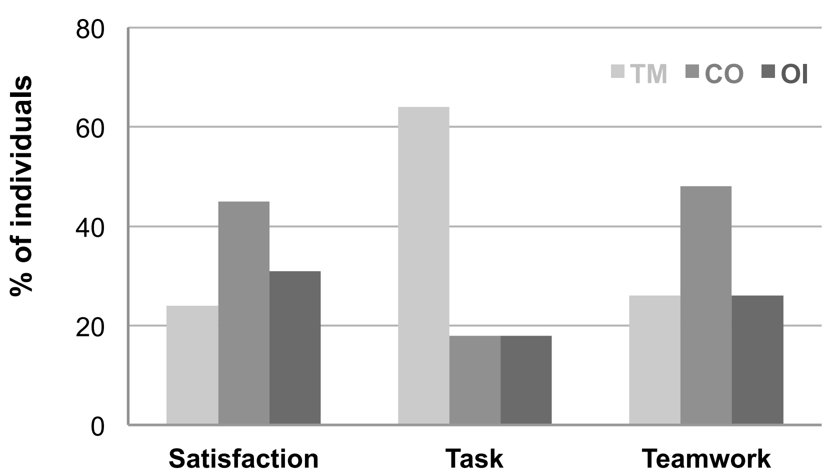

Figure 6: Leadership Orientation by situation

5) **At what stage in their career trajectory do engineers recognize the importance of skills associated with each orientation?**

For this question, we asked participants to identify when they first recognized the importance of various skills: technical skills (technical problem solving), social skills (team performance, social responsibility, self-awareness), and organizational skills (strategic planning, business savvy and organizational awareness). The results of this inquiry are illustrated in Figure 7 below. In high school, nearly half of the sample recognized the importance of technical skills, but very few saw the importance of social or organizational skills. While working on their engineering degrees, approximately three quarters of the sample saw the importance of technical skills and nearly half recognized the importance of social skills, but few saw the importance of organizational skills. By the time they had spent some time in the workplace, nearly all individuals saw the importance of all three sets of skills. Thus, it seems that experience with a particular skill set preceded most participants' recognition that the skill in question was important.

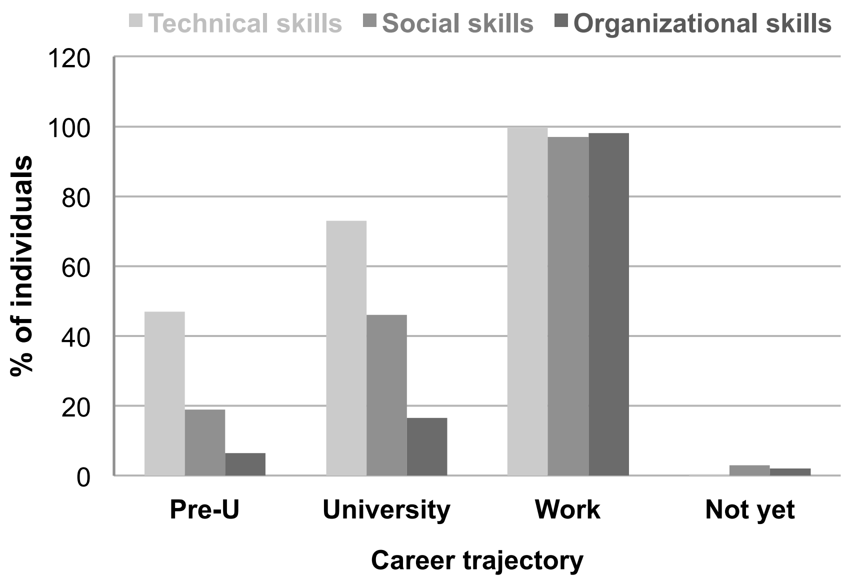

FIGURE 7: IMPORTANCE OF TECHNICAL, SOCIAL AND ORGANIZATIONAL SKILLS FIRST RECOGNIZED

6) What are the skills and traits associated with exemplary engineering leaders?

For this research question, participants were no longer answering survey questions about themselves. Rather, they were prompted to evaluate the skills and traits of engineering colleagues who exemplified each of the three leadership orientations. Please see Box 1 below for a list of survey items used to evaluate the skills of engineers leaders identified by their colleagues as exemplary leaders. The seven major categories parallel those used by Engineers Canada in their document "Core Engineering Competencies" [18]. We drew the 16 skills from the Canadian Engineering Accreditation Board's 12 Graduate Attributes (similar to ABET) [16] and supplemented this list with management and communication skills drawn from the Engineers Canada Core Engineering Competencies document [18].

BOX 1: SURVEY ITEMS USED TO EVALUATE THE SKILLS OF ENGINEERING LEADERSHIP EXEMPLARS

A= Applying engineering knowledge

- Solves problems using appropriate engineering principles

B= Using engineering tools, equipment or technology

- Uses appropriate tools, equipment and technology based on a sound understanding of these principles

C= Protecting the public interest

- Considers social, political and environmental implications of his/her work
- Works in ways that serve the public good
- Incorporates diversity and equity considerations into actions

D= Managing engineering activities

- Helps team members adapt to changing circumstances
- Works in ways that maximize the economic success of the business
- Plans and implements projects successfully
- Navigates organizational structures and politics

E= Communication

- Persuades others, generates buy-in
- Communicates engineering concepts to non-engineers
- Gives constructive feedback

F= Teamwork

- Resolves interpersonal conflict
- Cultivates productive and meaningful relationships

G= Life long learning

- Mentors and/or coaches others
- Takes actions to address gaps in knowledge, skills and abilities

Participants evaluated colleagues they identified as exemplars of technical mastery, collaborative optimization and organizational innovation on all 16 skills. The top three skills across the full sample are listed in descending order in Table 3. The letters beside each skill corresponds with categories generated by Engineers Canada in their document "Core Engineering Competencies" [50], while the grey shading identifies skills that made it into more than one top three list.

TABLE 3: TOP THREE SKILLS OF EXEMPLARY ENGINEERING LEADERS

Technical Mastery	**Collaborative Optimization**	**Organizational Innovation**
Technical problem solving (A)	Persuasive, generates buy-in (E)	Maximizes business success (D)
Tools & technology (B)	Cultivates relationships (F)	Considers social/environmental implications of work (C)
Mentoring (G)	Helps team adapt to change (D)	Persuasive, generates buy-in (E)

The fact that there was little overlap suggests that the engineering leadership orientations are conceptually distinct and that individuals who exemplify the orientations make complementary rather than overlapping contributions to their organization. While none of the exemplary leaders was rated poorly on any of the 16 skills, we found it instructive to identify areas of improvement for exemplars of each leadership orientation. This data is listed in Table 4 below.

TABLE 4: THREE AREAS OF IMPROVEMENT FOR EXEMPLARY ENGINEERING LEADERS

Technical Mastery	Collaborative Optimization	Organizational Innovation
Conflict resolution (F)	Tools & technology (A)	Conflict resolution (F)
Organizational Savvy (D)	Technical problem solving (B)	Helps teams adapt to change (F)
Persuasive, generates buy-in (E)	Fills gaps in knowledge (G)	Planning & Implementation (D)

Other than conflict resolution, none of the bottom three competencies overlaps across leadership orientations. If we compare table 3 with table 4, it becomes clear that exemplary leaders of each orientation have skills that coincide with weakness of exemplary leaders of the other two orientations. The complementary nature of these skill sets provides an interesting professional development opportunity to engineers interested in learning from their peers. Technical masters can mentor collaborative optimizers through technical problem solving challenges; collaborative optimizers can support technical masters and organizational innovators with teamwork and conflict resolution skills; and organizational innovators can help technical masters pay attention to the organizational and societal context in which they work.

Competencies aside, it is often helpful to characterize the traits of exemplary leaders so that human resource professionals, project managers and directors can more easily and transparently recognize leadership potential among engineering personnel. Please see Table 5 for the top five traits of engineers identified by their peers as exemplars of technical mastery, collaborative optimization and organizational innovation. The full list of 22 traits emerged from a brainstorming session held by the three researchers working on this project.

TABLE 5: TOP FIVE TRAITS OF ENGINEERING LEADERSHIP EXEMPLARS

Technical Mastery	Collaborative Optimization	Organizational Innovation
Analytical	Has Integrity	Visionary
Detail oriented	Takes initiative	Creative
Has Integrity	Confident	Has Integrity
Task-oriented	Likeable	Takes initiative
Confident	Resourceful	Confident

In contrast to our finding that the most highly rated engineering competencies differed between engineering leadership exemplars, it is interesting to note the considerable overlap in traits across the three orientations. That is, regardless of the orientation, exemplary leaders demonstrate confidence, integrity and initiative.

Conclusions & Implications for Engineering Education

Our data suggest five main conclusions:

1) Engineering leadership orientations shift over time and across situations. They are not immutable qualities of individuals.
2) Women and novice engineers were slightly more likely than men and more experienced engineers to prioritize collaborative optimization over the other two orientations.
3) Concrete experiences with technical skills, social skills and organizational skills tend to precede engineers' recognition of the importance of these skills.

4) Engineers identified by their peers as exemplary technical, team and organizational leaders demonstrate complementary sets of core engineering competencies (as defined by national accreditation bodies such as ABET and CEAB).
5) Engineers identified by their peers as exemplary leaders tend to demonstrate confidence, integrity and initiative.

Before we can identify any practical implications of our study, it is important to recall the methodological limitations with which we began. Our findings are preliminary trends rather than empirically supported patterns achieving statistical significance. Still, if the trends we have identified in our findings hold true for a larger population, five implications for engineering education follow:

1) If engineering leadership orientations shift over time and across situation, it would be helpful for engineering educators to supplement conversations about fixed leadership "styles" with conversations about situational and developmental trends in leadership. In addition to exposing students to research on situational leadership [54], it behoves us as engineering educators to challenge the human tendency to categorize ourselves and others according to our strengths and weaknesses. For example, two popular inventories used with engineers at our institution are the Bolton and Bolton work style inventory and the Myers Briggs Personality Type Inventory. While these two tools provide students with useful insights about their personalities, behaviours and habits of mind, our findings suggest that engineering educators who use these tools with their students would be well advised to discuss them as temporally-contextualized orientations rather than immutable categories. If they can critically examine these two typologies and expose students to multiple ways of influencing, supporting and relating to their colleagues, the next generation of engineers will learn the value and practice of flexibility while opening themselves to qualitatively diverse forms of professional development.

2) If it proves to be the case that female engineers, on average, are more likely to prioritize collaborative projects over autonomous technical problem solving exercises, faculties of engineering interested in improving their retention of women and collaboratively oriented men might achieve this goal, in part, by increasing their provision of high quality teamwork opportunities. This educational innovation is likely to be wide reaching as novice engineers of both sexes in our sample tended to accord high value to teamwork.

3) Since the majority of survey participants did not recognize the importance of organizational skills until they had accrued some workplace experience, it is important for us as engineering educators to infuse relevant organizational experiences into the curriculum. Leadership strategies that may feel uncomfortable to undergraduate students will become increasingly relevant as they gain experience with organizational contexts outside of the university classroom, but it can be overwhelming for them to wait until they leave university to learn these skills. Two historically popular strategies for integrating workplace learning into engineering education are semester long co-op terms and 16-month internships. If these two options are not feasible in a particular institutional context, it is possible to infuse meaningful experiential educational opportunities into the curriculum through capstone design courses, realistic case studies facilitated by

professional engineers, mentorship experiences, and interviews with engineering leaders across the career trajectory. Each of these activities can be used to help engineering students value and develop organizational skills before they secure their first job.

4) While the relatively recent introduction of accreditation bodies (ABET, CEAB) to engineering education may feel like a constraint to many professors, the graduate attributes generated by these bodies can be used creatively as a pedagogical framework. When used as a regulatory checklist, the imposition of these attributes breeds frustration. If, however, faculty examine how full mastery of their disciplines includes foundational engineering knowledge, teamwork, communication, professionalism, ethics, project management, organizational awareness, environmental sensitivity, and life long learning, they will engage a wider range of students in their discipline. University and college administrators can facilitate this process by asking department chairs to indicate how their existing courses and programs map on to these attributes. Once they have completed this process, deans and associate deans can examine the gaps at a faculty-wide level and provide small seed grants to individual instructors, researchers and staff interested in finding ways to address the missing attributes. Cross-departmental workshops can then be used to spread the use of these initiatives to willing instructors. This strategy is currently underway at the University of Toronto through annual "Engineering Instructional Innovation Program."

5) If confidence, integrity and initiative are highly rated traits of engineering leaders, it behoves us as engineering educators to help students build confidence, reflect on the integrity of their daily actions, and engage in co-curricular opportunities to demonstrate their initiative. The somewhat abstract nature of these traits would be well served by education grounded in concrete experiences and activities [55].

These five conclusions and corresponding implications suggest that engineering leadership develops over time and across situations, looks different across demographic markers, depends on a wide range of experiences in different engineering contexts, corresponds well with a wide range of graduate attributes, and requires the development of confidence, integrity and initiative. In short, it ebbs and flows across social, organizational and demographic contexts.

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