What is Engineering Leadership? A Proposed Definition

Robyn Paul, University of Calgary

Robyn Paul is the Program Evaluation and Planning Specialist in the Schulich School of Engineering at the University of Calgary. She is responsible for supporting the decision-making and reporting needs of SSE, particularly those related to accreditation and the teaching and learning processes. Robyn is also finishing up her master's thesis in engineering education where she is looking at the impact of engineering leadership development on career success.

Dr. Arindom Sen, University of Calgary

Dr. Sen is the Associate Dean (Student Professional Development) in the Schulich School of Engineering at the University of Calgary. He is responsible for co-curricular programming related to professional skills development. He is also an award-winning teacher, a fellow of Engineers Canada and a professor of chemical engineering with a research focus in medical and industrial bioprocessing.

Emily Wyatt, University of Calgary: Schulich School of Engineering

Emily Wyatt is the Specialist for Diversity & Student Professional Development in the Schulich School of Engineering at the University of Calgary. Her role focuses on student engagement, leadership, and diversity & inclusion initiatives for current and prospective engineering students. Emily holds a master's degree in higher education and student development.

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Abstract

In response to the demand for engineering graduates with stronger leadership skills, many engineering leadership development programs have been established around the world. Many of the best practices in such programs are similar to those in general leadership programs, and there seems to be a lack of understanding of how to define engineering leadership, and explain how it differs from general leadership. To address this issue, a survey was distributed to 163 participants (87% students, 13% alumni from a Canadian University) asking, "*How do you define leadership in an engineering context?"* The results were analyzed using qualitative content analysis, and four themes emerged: lead and influence others, personal effectiveness, engineering competency, and collaboration. Based on these results, combined with relevant knowledge from literature, this paper proposes a definition of engineering leadership that highlights the importance of both the engineering and the leadership aspects, thereby providing clearer direction for fostering leadership skills in our future engineers. The definition will provide engineering leadership educators with a better understanding of how to emphasize the importance of engineering leadership, and how to integrate it into a general engineering education curriculum.

Introduction

As societies rapidly advance, and populations grow to unprecedented levels, engineers are faced with solving increasingly complex problems of a magnitude not previously seen. Solving these problems will require more than just the technical and analytical abilities that have traditionally been taught in engineering undergraduate programs. Rather, engineers of the future will be required to possess key non-technical attributes which enable them to also understand and navigate social, political, economic, cultural, environmental, and ethical aspects of the technical projects on which they are working [1]. Engineering educators must meet the challenge of providing their students with professional attributes and essential critical thinking skills to create the engineering leaders and innovators of tomorrow [2].

Engineering leadership development programs have become increasingly popular as there is a recognized demand for engineers who are more well-rounded and possess leadership attributes [3]. A review of the literature related to these programs show that they aim to provide professional skills such as communication, innovation, creativity, execution, personal drive, and teamwork [4]. National engineering bodies have also recognized this need to educate engineers in leadership. In the report entitled "The Engineer of 2020", leadership was one of the key attributes mentioned [5, p. 53]. CDIO (Conceive-Design-Implement-Operate), an innovative educational framework for engineering, also addresses the need for engineering leadership in their most recent syllabus update [6, p. 69]. The Canadian book, *Fundamental Competencies for the 21st Century Engineers*, has also recognized this need, and has added leadership as an essential competency for engineers in their most recent edition [7]. The attribute of leadership has also been included in the new student outcomes for ABET (Accreditation Board for

Engineering and Technology), which will become effective in the 2019-2020 accreditation cycle (replacing the "a-k" outcomes). Students must be able to "function effectively on a team whose members together provide *leadership*, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives" [8, p. 40].

Despite the wide recognition that leadership attributes are needed in engineering graduates, there still remains a lack of clarity on the definition of engineering leadership. Specifically, there appears to be confusion in trying to explain the engineering component in engineering leadership and articulating key differences between general leadership and engineering leadership. This research paper aims to propose a definition of engineering leadership. The definition will be based on qualitative analysis of the results from a survey distributed in a Canadian engineering context, and informed by relevant literature. Much of this research was carried out as part of a graduate degree project [9].

Background: Leadership in Literature

Leadership has been researched for centuries and is said to be "one of the most observed and least understood phenomena on the earth" [10, p. 2]. In literature, leadership theories and definitions are often categorized into different models or styles. Within these vast arrays of theories and models, there is an extensive amount of literature on defining leadership. For example, a thorough review of 160 articles defining leadership provided a detailed integrative definition of leadership that is over 1600 words [11]. Their definition of leadership contains 90 variables that make up the whole of leadership, which provides a detailed view on the breadth and scope of leadership.

Rather than delving into the immense depth and breadth of leadership, this section will focus on key concepts from a broader perspective. Four elements of leadership consistently appear across modern literature: leadership is a process, requires collaboration, entails problem solving, and results in transformative change. Each of these key elements will be described in the next sections. However, before going further, it is important to acknowledge that when discussing leadership, the question of the differences and similarities between leadership and management often arises.

Management can be described as a building activity and is used to maintain stability, whereas leadership is a process of unfolding, and of energy; leadership is all about change [12]. Management skills are essential for success in leadership, and leaders must perform managerial functions; however, leadership goes beyond these [13], [14]. Although there are clear differences, it is also evident that management and leadership overlap: "both processes involve influencing a group of individuals toward goal attainment" [15]. For the purpose of this paper, there is an understanding that there is some amount of overlap; however, the focus will be on leadership.

Leadership is a Process

It is important to consider that leadership is a continuous social process [12]. Leadership is a transactional process that occurs between the leader and the followers, where a leader affects and is affected by followers [15]. When defined as a process, leadership is no longer simply about the person in charge; rather, it is a dynamic collective of individual wills and individual needs [12]. To participate in leadership, both leaders and followers must participate in a process, not an event, and the characteristic of the leader's relationship with the followers must be considered [16]. It is therefore also important to consider *followership*. Followership can be defined as the "conscious and unconscious behaviours of persons and groups in support of the goals and desires of a leader" [17]. Leadership can only emerge when there is strong followership, where the followers trust the leader and are able to be flexible and adaptable in meeting the needs of the group. To achieve this level of trust between leaders and followers, one must consider the fluidity between the roles of leader and follower. A leader must understand when it is appropriate to step into the role of follower, and have a desire to become a follower. A follower must also be capable and desirous of leading [17].

Leadership Requires Collaboration

Northouse defines leadership as a "process whereby an individual influences a group of individuals to achieve a common goal" [15, p. 6]. He describes a relationship of two key elements whereby leadership involves influence, and leadership occurs in groups. Without either of these, leadership would not exist. When emphasizing that leadership requires collaboration, this highlights the fact that leadership is *not* power. When power is applied, this only meets the goals of the leader, whereas leadership is about motivating and engaging followers towards a common goal [17]. Leadership is about fostering trust through a mutual partnership, not a hierarchical relationship [19].

Leadership Entails Problem Solving

Problem solving is becoming increasingly important in the modern complex and globalized society. Leadership within these creative and innovative organizations, therefore, must emphasize the importance of problem solving [18]. Leadership is a process that must identify and assess problems, and then provide the "catalyst for the adaptive action executed by the followers/group which resolves the problem" [16]. Leaders must facilitate and promote followers to engage in creative problem solving activities, including divergent idea generation and convergent idea evaluation [20].

Leadership is Transformative

Leadership results in transformative change; it is a process of adaptation and evolution, and it is "deviation from convention" [12]. Leadership is when leaders and followers engage together in adaptive action, otherwise actions are simply leaders exerting than power over followers [16].

The term *transformational leadership* was first introduced in 1978 and provides leaders and followers with a purpose beyond short-term goals, focusing on higher order intrinsic needs. The transformational style of leadership has been shown to have stronger outcomes in terms of effectiveness, satisfaction, commitment and extra effort, all of which lead to greater change and problem solving achievements [21].

Engineering Leadership in Literature

With the rise of recognition in the importance of engineering leadership, the field of research has seen substantial growth, particularly over the past 5-10 years [3]. With this growth, scholars and engineering governing bodies have worked towards a definition of engineering leadership. A summary of examples is provided in Table 1. Many additional scholars have done great work defining the skills of leadership and leadership development (ex. [22], [23], [24]); however, this summary specifically looks to highlight definitions of engineering leadership from literature.

Table 1. Summary of Engineering Leadership Definitions Found in Literature.

Source	Definition
[25, p. 504]	"Engineering [leadership] is the process of envisioning, designing, developing, and supporting new products and services to a set of requirements, within budget, and to a schedule with acceptable levels of risk to support the strategic objectives of an organization." *Note: This paper focused on engineering management, but the tone is very much towards teaching engineering management to "engage technical leadership towards business success" therefore the definition was included.*
[26, pp. 17, 145]	Outcome 20 (Leadership): "Organize and direct the efforts of a group." "In a broad sense leadership is developing and engaging others in a common vision, clearly planning and organizing resources, developing and maintaining trust, sharing perspectives, inspiring creativity, heightening motivation, and being sensitive to competing needs. Leadership is the art and science of influencing others toward accomplishing common goals and does not necessarily require a formal role or position within a group."
[27, p. 8]	"Engineering Leadership is the ability to lead a group of engineers and technical personnel responsible for creating, designing, developing, implementing, and evaluating products, systems, or services."
[28, p. 2]	"In an engineering context, leadership incorporates a number of capabilities that are critical to function at a professional level. These capabilities include the ability to assess risk and take initiative, the willingness to make decisions in the face of uncertainty, a sense of urgency and the will to deliver on time in the face of constraints or obstacles, resourcefulness and flexibility, trust and loyalty in a team setting, and the ability to relate to others. In a broader context, engineers need leadership skills so that later in their careers they can develop the ability to help create and communicate a vision for the future and the ability to help shape public policy. These leadership capabilities are essential for the professional practice of engineering and for the protection of public health, safety, and welfare."

[29, p. 56]	"Looking at the context and application of leadership in engineering, it is the ability of the leader to guide the whole project and influence other people to meet the schedules and customer quality requirements while working within specified time and budget constraints."
[22, p. 1]	"In this program, engineering leadership is defined as the technical leadership of change: the innovative conception, design and implementation of new products / processes / projects / materials / molecules / software / systems, supported by the invention of enabling technologies, to meet the needs of customers and society."
[6, p. 68]	"Leadership refers to the role of helping to organize effort, create vision, and facilitate the work of others."

There are some commonalities observed across the definitions in Table 1. They almost all mention the ability to influence others and direct a group, for example, "helping to organize effort, create vision, and facilitate the work of others" [6]. Most definitions also include the ability to produce a deliverable based on constraints, for example "to meet the schedules and customer quality requirements while working within specified time and budget constraints" [29]. Other concepts mentioned multiple times include creating a vision, assessing risk, and building trust.

Additionally, a study by Rottmann, Sacks and Reeve [30] grounded leadership theory in the professional experiences of engineers. Their results found that engineers value their work based on its technical precision, and perceived leadership to be imprecise, emotional, impractical and elitist. This dissonance between their identity and their beliefs about leadership meant they felt leadership was just "not us." However, in their analysis, the authors were able to parse language used by the engineering professionals which clustered to three orientations of engineering leadership: technical mastery, collaborative optimization, and organizational innovation. Their findings emphasized the importance of distinguishing engineering leadership from general leadership. Leadership for engineers needs to be routed in their engineering identity.

Methods

Data Collection

All participants were recruited through surveys, which were distributed to a variety of audiences for the purpose of this research. Participation in all surveys was voluntary, and they were distributed to the following audiences. A summary of the demographics is shown in Table 2.

- Paper-based surveys distributed in 2014 and 2015 at student leadership conferences
- Online surveys distributed in 2015 and 2016 to engineering leadership program participants
- Online survey distributed in 2016 to all first and final year engineering students
- Online survey distributed in 2018 to alumni who were student leaders between 2005-2012

Excluding the surveys distributed to the first and final-year students (n = 36 or 22% of respondents), participants were current or previous student leaders, where they held a leadership position as an executive member on a student club, team or association. All participants were also current or previous students of the Schulich School of Engineering, University of Calgary.

Table 2. Research participants and demographics.

		Gender			Discipline					
	n	F	M	-	Chem	Civil	Elec.	Geo.	Mech.	N/A
Current Students	141	73 51.8%	66 46.8%	2 1.6%	31 22.0%	25 17.7%	32 22.7%	8 5.7%	33 23.4%	12 8.5%
Alumni	22	10 45.5%	10 45.5%	2 9.1%	2 9.1%	6 27.3%	5 22.7%	5 22.7%	4 18.2%	0 0%

Survey Design

Each of the surveys included a variety of questions, and the focus of this paper is on one specific question. Across all surveys, the first question was an open-ended text box: *How would you define leadership in an engineering context?* This style of question was chosen to give the participants flexibility in their definitions. A conscious decision was made to place it first on the survey to minimize the bias of the participants obtaining ideas from the other survey items, such as engineering leadership self-efficacy assessments and career success items.

Qualitative Content Analysis

The survey responses were analyzed using qualitative content analysis. This methodology was first introduced in 1998 and it can be described as "a research method for subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns" [31, p. 1278], or more simply, it is "qualitative data reduction and sense making" [32, p. 453]. The outcome of the qualitative content analysis process is concepts or categories which describe a phenomenon [33], in this case, defining engineering leadership.

During the open coding analysis process, definitions were reviewed, interpreted, and assigned codes. A good code is sufficiently precise, represents the data it came from, and is relevant to the research question. Categories of codes are freely generated during the open coding process, and afterwards they are grouped into higher order headings with the aim of reducing the number of categories by combining those that are similar [33]. For the purpose of this research, the open coding process was carried out as shown in Figure 1:

1. Definitions were randomized and demographics hidden to reduce bias.
2. Each definition was coded individually.
3. Codes were grouped into similar concepts (ex. *teamwork*, *mentor*, *take initiative*)
4. Concepts were refined:
    a. Codes within each concept were compared and contrasted, observed dissimilarities caused adjustments (ex. *responsible* was split into two concepts: *ethics / responsibility* and *take responsibility / be accountable*)

b. Each of the concepts were compared and contrasted, similar concepts were combined (ex. *positive environment* and *open input from everyone* were combined to be *safe, positive, and open environment*).
c. Each definition's assignment of codes into concepts was reviewed again to ensure changes in the concepts were reflected.
d. Any concepts with less than five codes were reviewed and combined (ex. *encourage* and *empower* were combined together)

Finally, the last step of the analysis is abstraction, where similar concepts themes are grouped together into higher order headings. For example, *mentor*, *set example*, and *trustworthy / authentic* were grouped under the category *be a role model*. The abstraction continues as far as is reasonable and is possible, in order to best achieve data reduction and sense-making [33]. For this research, the abstraction process continued to the point until the categories were grouped into higher-order themes, as depicted in Figure 1.

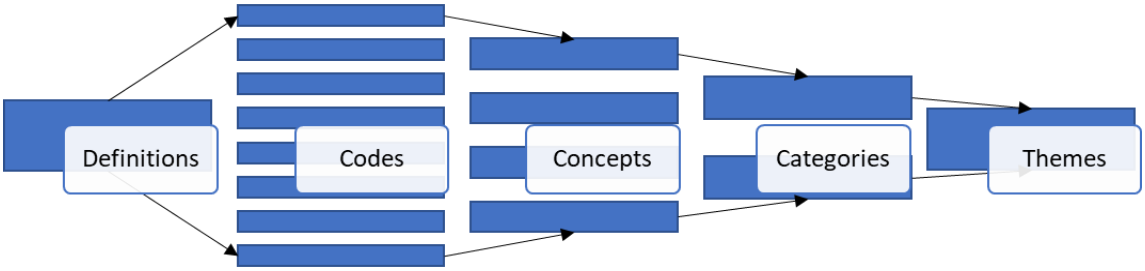

Figure 1. The qualitative content analysis process used to analyze the engineering leadership definitions.

Findings: Engineering Leadership Definition Survey

From the surveys collected, 163 definitions were analyzed. Definitions contained a total of 4408 words, averaging 27 words with a range of 2 to 113 words. When coded, there were 689 codes total, with definitions averaging four codes, ranging from 1 to 15 codes each. A word cloud showing the most commonly used words in the definitions is shown in Figure 2.

Figure 2. Word cloud visualizing the most commonly used words across the engineering leadership definitions.

Themes and Categories of Engineering Leadership

As depicted in Figure 1, the definitions were broken into *codes*, the codes were grouped into *concepts*, which were grouped into *categories*, and finally the categories were grouped into *themes*. From the initial *689 codes*, these were grouped into 81 concepts, which after refinement was reduced down to *54 concepts*. Through abstraction, these 54 concepts were grouped into *10 categories* and finally into *four themes*. Figure 3 below shows a summary of the categories and themes. Each of the four themes is described with examples in the next paragraphs.

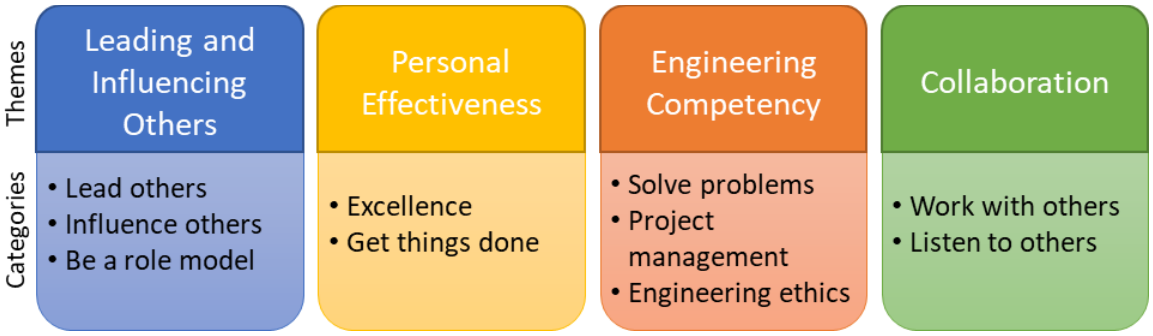

Figure 3. Summary of the themes and categories which emerged from the engineering leadership definitions.

Leading and Influencing Others

This theme included three categories: *lead others*, *influence others*, and *be a role model*. The *lead others* category included a variety of verbs used to describe the act of leading others, such as lead, direct, control, guide, coordinate, and manage. Also contained within this category was the concept of setting a vision or direction for others, for example engineering leadership is "the ability to get multiple people working towards a common goal."

The *influence others* category was focused on building others up and included verbs such as encourage, empower, help, inspire, influence, motivate, teach, and support. For example, engineering leadership is "inspiring and motivating team oriented individuals to accomplish a particular goal while helping to unlock their skills and potential."

The final category in this theme, *be a role model*, included concepts such as mentorship, setting a good example, being humble, authenticity, and trustworthiness. For example, leadership in an engineering context is "leading by example, being a role model, and getting the job done and empowering others to do the same."

Personal Effectiveness

This theme included two categories: *excellence* and *getting things done*. The *excellence* category emphasized engineering leaders should be good at what they do. Concepts such as successful, effective, confident, and technical expertise were included here. Many definitions also emphasized the importance of having a wide variety of skills and being able to synthesize these skills together. For example, one definition was that engineering leaders are able to be "effective,

creative and innovative but to still respect all of the analytical skills behind design." Other concepts in the *excellence* category included that engineering leaders should always do their best and "go above and beyond", and that they should be "continuously targeting opportunities for growth and learning".

The second category in this theme, *getting things done*, included concepts such as take initiative, take action, make decisions, take responsibility, be accountable, and be willing to do what others will not. Also included within this category, was the idea that engineering leaders take action to improve the world around them. For example, "Leadership is taking the initiative to find new opportunities to better someone's life."

Engineering Competency

This theme included three categories, *solving problems, project management,* and *engineering ethics.* One of the most common concepts across all definitions was problem solving, and the ability to "work with others to solve problems." Additional concepts related to problem solving include technology, complex problems, innovation, and the approach to problem solving (being able to define, structure, analyze and systematically solve problems).

The second category, *project management,* included related concepts such as time management, task management, seeing the big picture, being organized and being resourceful. For example, "leadership is the ability to look at the big picture, to coordinate people and resources in the hopes of accomplishing a project."

The *engineering ethics* category included concepts which focused on the code of ethics, being a responsible engineer, safety, and understanding the impact on society. For example, engineering leaders have the "ability to take action, and inspire/direct action in others, which leads to safe, technically sound, and practical engineering solutions that follows professional practice standards and improves society in a meaningful way."

Collaboration

The final theme included two categories, *work with others* and *listen to others.* The *work with others* category included the concepts teamwork, communication, making teams more effective, and understanding individual strengths of team members. For example, an engineering leader is "an individual who, when in a group, is able to lead their group members and use their full potential in order to get maximum production from the whole group."

The *listen to others* category emphasized the importance of being able to listen, create a safe and open environment, take input from others, and be understanding. For example, "leadership is the ability to gather thoughts and ideas from everyone, and construct a main idea containing all of the elements gathered."

Comparing Demographics across Themes and Categories

Demographics were grouped in two main ways: female (n = 83) and male (n = 76) participants; and current student (n = 141) and alumni (n = 22). Across the four themes, female participants and student participants tended to put more emphasis on the theme *Leading and Influencing Others,* whereas male participants and alumni participants emphasized the theme *Engineering Competency.* Within the categories, female participants talked more about *building others up* whereas male participants discussed *working with others.* However, overall it is important to consider that these results are based on a population that was mostly students (87%), and based in a Canadian, English-speaking context. Further work to validate and refine these themes and categories is important, particularly to integrate more perspectives from diverse industry.

Proposed Definition of Engineering leadership

Three sources of information were gathered and analyzed to inform a proposed definition of engineering leadership. First, the results from the qualitative content analysis provided an understanding of engineering leadership (based on majority student leader respondents in a Canadian context). Second, the general literature emphasized that leadership is a process, requires collaboration, entails problems solving, and is transformative. Next, the engineering literature emphasized that engineering leadership is about influencing others or directing a group, and producing a deliverable based on constraints. Additionally, the engineering identity study concluded that engineers display leadership through their technical mastery, collaborative optimization, and organizational innovation [30]. A summary categorizing the results into the *what, who, how* and *why* of leadership can be found in Table 3.

Table 3. Summary of key engineering leadership elements from literature & survey results.

	What?	**Who?**	**How?**	**Why?**
Leadership Literature	• Process		• Problem solving • Collaboration	• Transformative
Engineering Leadership Literature	• Influence	• Technical mastery	• Collaborative optimization	• Deliverables • Organizational innovation
Engineering Leadership Survey	• Lead / influence others	• Personal effectiveness	• Collaboration • Engineering competency	

From this, the following definition is proposed:

> ***Engineering leadership is an approach that influences others to effectively collaborate and solve problems.*** *Engineering leadership requires technical expertise, authenticity, personal effectiveness, and the ability to synthesize diverse expertise and skillsets. Through engineering leadership, individuals and groups implement transformative change and innovation to positively influence technologies, organizations, communities, society, and the world at large.*

The definition contains three sentences. The first sentence covers *what* is engineering leadership (approach that influences others) and *how* it is accomplished (collaborating to solve problems). This sentence is similar to the proposed definition of leadership from Northouse [15]. It is important to note that the word *process* was not used as it has a very specific meaning within engineering, and there is even a discipline of *process engineering*. Thus, the word *approach* was used instead to characterize that leadership is not a singular event, but rather a continuous activity.

This first sentence arguably is applicable to leadership in any situation, describing the *what* and the *how* of leadership generally. Whereas the next two sentences provide the engineering context. The second sentence summarizes the *who* of engineering leadership, listing some of the skills required by leaders and followers in order to participate in engineering leadership. The last sentence then provides the *why* of engineering leadership, which speaks to engineering innovation and service to society.

Discussion and Conclusion

Engineering leadership is a growing field of research with a lack of clarity and limited synchronicity. This proposed definition provides a foundation for a clear understanding of the *what*, the *how*, the *who* and the *why* of engineering leadership. Education institutions and industry organizations looking to design or revamp engineering leadership programs can also use this definition to provide guidance on the vision and goals of their programs. The mode of delivery for engineering leadership is also important to consider. Although faculty members often believe leadership skills are best developed in extracurricular experiences [34], these assumptions may be misguided, as curricular experiences appear to have a stronger correlation to students' self-reported leadership skills [35]. It is therefore important to consider how this definition can provide guidance on integrating leadership into the engineering curriculum.

Our proposed definition of leadership was constructed based on the literature of leadership, engineering leadership, and the results of a survey. The definition provides a better understanding of how to emphasize the importance of engineering leadership, and how to approach leadership development within the engineering education curriculum.

It is important to consider that the proposed definition emerged from a survey of predominantly students from a Canadian, English-speaking population. In future work, additional feedback should be gathered from diverse groups, including more industry professionals, faculty members, and other input groups. This feedback would enable us to evaluate if the definition resonates, or if there are any key elements missing from the definition. Consulting a broader audience would help to refine and generalize the definition of engineering leadership.

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