Perspectives on Defining Engineering Leadership

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ABSTRACT

Leadership has been studied for centuries and there are many definitions and theories of leadership that have evolved over time. However, only recently has the term engineering leadership been introduced and there is a lack of a clear definition. A stronger understanding of the different perspectives of this term will help institutions to develop and improve engineering leadership education programs. The aim of this research is to answer the following: from the perspective of engineering students, what is engineering leadership? This paper provides a summary of the results from a pilot study conducted with a group of undergraduate students. Engineering students were surveyed at the beginning and end of their semester to understand their perspective on engineering leadership. The engineering leadership definition responses were analyzed using qualitative content analysis. Three main themes of engineering leadership were generated: Strong Character, Team Dynamics and Technical, and each of these three broad areas were equally emphasized by the students. A comparison of the results from the beginning to the end of the semester showed a reduced emphasis on the required technical competence of engineering leaders. The findings from this could be useful to develop and improve engineering leadership education programs, and to provide groundwork for further research.

KEYWORDS

Engineering Leadership, Leadership Skills, Student Perspective, Qualitative Content Analysis, CDIO Syllabus Extension, Standards: 2,7

INTRODUCTION

Engineers are not only involved in the technical aspects of projects, but are expected to understand the broader picture, often taking on roles as leaders. In order to reflect the changing expectations of engineers, the second edition of "Rethinking Engineering Education" included an extension to the CDIO Syllabus for Leadership (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014).. One of the difficulties in the field of engineering leadership education is the need to clearly define the term (Ahn, Cox, London, Cekic, & Zhu, 2014). A stronger understanding of the term *engineering leadership* will help institutions to develop and improve engineering leadership education programs and to achieve the CDIO Syllabus for Leadership.

The aim of this research is to determine the student leader's perspective of engineering leadership. This paper provides a summary of the results from a pilot study conducted with a group of undergraduate student leaders, both at the beginning and end of a school year. To begin, current engineering leadership research and definitions will be discussed.

DEFINING ENGINEERING LEADERSHIP

Although leadership has been studied for centuries and hundreds of definitions have been proposed (Faket et al, 2014), the complex and specialized nature of engineering requires an understanding of leadership specifically within the engineering context (Crawley, Lucas, Malmqvist, & Brodeur, 2011). Engineering leadership has seen an increased growth and development over the past decade. The following will focus on definitions provided by three well-known organizations.

A definition of engineering leadership provided by the Bernard M. Gordon-MIT Engineering Leadership Program (GEL) simply is “the technical leadership of change” (Gordon-MIT, 2011). The GEL definition is further clarified to include the innovation, implementation and invention of products and enabling technologies to meet the needs of society (Gordon-MIT, 2011).

The National Society of Professional Engineers (NSPE) outlined the need for preparing students for the professional engineering practice by providing them with the “ability to apply principles of leadership” (NSPE, 2010). The NSPE provided the following definition that defines engineering leadership through a list of required capabilities:

> “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.” (NSPE, 2010, p. 1)

Lastly, as previously mentioned, the CDIO Syllabus recently added an extension to include leadership, defining it as “the role of helping to organize effort, create vision, and facilitate the work of others” (Crawley et al., 2014, p. 68). Specifically within an engineering context, CDIO specifies that the best approaches to leadership tend to focus on an environment of “change, uncertainty, and the deliberate pursuit of invention” (Crawley et al., 2011). Also, it is clarified that leadership and the engineering curriculum should not be orthogonal, but rather the skills required for both engineering and leadership should have an extensive amount of overlap.

Overall, these definitions provide three viewpoints to give a basic understanding of leadership within an engineering context, and will be used as reference definitions for this paper.

POPULATION SURVEYED

Context: Maier Student Leadership Conference

Surveys were distributed at two annual student leadership conferences during the Schulich School of Engineering Maier Student Leadership Program (for more details on the program please see Cowe Falls, Paul, & Aker (2015)). The first conference occurred near the beginning of the school year during the first semester and will be referenced as the “Fall 2014 Conference” (F14). The second conference occurred near the end of the school year during the second semester and will be referenced as the “Winter 2015 Conference” (W15). There was approximately seven months between the two conferences.

The goal of the F14 conference was to set the students up for success for their extracurricular activities during the year. This conference provided an opportunity for students who were interested in leadership, or had some leadership experience, to learn how to be an effective leader in engineering. The goal of the W15 conference was to reflect on the activities throughout the past year, to plan for the upcoming year, and to provide guidance on succession procedures for the new incoming leaders. During the W15 conference, the audience was mostly students who had been in leadership positions throughout that school year.

Participant Demographics

Participation in the survey was optional, and the details of the participants can be seen below in Table 1. For the F14 survey, the response rate was approximately 56% (28 of 50 attendees) and for the W15 survey, the response rate was approximately 74% (26 of 35 attendees).

Table 1. Summary of participant demographics.

		Fall 2014 (n = 28)		Winter 2015 (n = 26)	
		n	%	n	%
Year of Study	First	4	14%	0	0%
	Second	6	21%	10	39%
	Third	11	39%	8	31%
	Fourth+	7	25%	8	31%
Gender	Female	20	71%	14	54%
	Male	8	29%	12	46%
Previous Conference Attendee	Yes	12	43%	17	65%
	No	16	57%	9	35%

In F14, the greatest number of participants were in third year, whereas in W15 the greatest number of participants were in second year. It is also notable that no first year students participated in the W15 survey. The F14 conference had a much higher percentage of females at more than two thirds, whereas in W15 the split was closer to 50/50.

Most notably, more than half of the F14 participants were at their first leadership conference, whereas just over one third were attending for the first time in W15. This indicates that the students at the W15 conference had an overall higher level of leadership experience than the students who had attended the F14 conference.

It is important to mention that as the participants were attendees of a leadership conference, they likely had previous knowledge of leadership or an interest in leadership. Although this may impact the data, the methodology and results will be valuable for this preliminary pilot study. When the pilot study is expanded, this will provide more significant results and allow the data to be further broken down to compare the results from different demographics.

Another area to address is the potential cultural bias of this study’s findings. Although ethnical background data was not collected, a high percentage of the participants (close to half) were observed to be from minority ethnic groups including Asia and the Middle East, but almost all North American born. One’s perception of leadership can be heavily influenced by cultural heritage, thus the results from this study should be interpreted as a Canadian perspective.

SURVEY CONTENT

The survey consisted of two parts, however the focus on this paper will be on the first part of the survey which was seeking to determine a student-based definition of engineering leadership. This part included an open-ended question: *How would you define the term "leadership" in an engineering context?* This style of question was chosen in order to give the participants flexibility in their answers. Also, a conscious decision was made to place it first on the survey in order to minimize the bias of the participants obtaining ideas from the items in the skills questionnaire.

The second part of the survey asked the students to do a self-assessment of their own leadership abilities. This part included a skills questionnaire that was developed based on the survey instrument created by Ahn et al. (2014). Ahn et al.'s survey contained 45 items specifically designed to measure outcomes in engineering undergraduate students related to leadership, adaptability to change, and synthesis abilities. Twenty of these items, principally the ones directly related to leadership, were chosen for the skills questionnaire (*e.g. I independently initiate new individual or team projects*). The participants were asked to rank the extent to which they embodied each statement on a 4-point Likert scale. The results from the self-assessment are not provided in this paper (please look at Paul & Cowe Falls (2015)).

ANALYSIS METHOD

Qualitative content analysis methods were used to analyze the definitions. This methodology can be defined as "qualitative data reduction and sense making" (Zhang & Wildemuth, 2009). Content analysis was chosen as it provided a systematic method to analyze the definitions of engineering leadership provided by the students, and make sense of the data.

The three phases qualitative content analysis were followed: preparing, organizing and reporting (Elo & Kyngäs, 2008). During the preparation phase, the unit of analysis was defined in order to consistently code the data. The unit of analysis selected was *a single concept,* typically a verb / subject / context (ex. work / to common goal / as team). Next, during the organizing phase the 54 definitions were coded using this unit of analysis for 1-10 per definition. The entire set of codes was then compiled for a total of 92 codes from F14 and 119 codes from W15 (see summary in Table 2). Similar codes were grouped into headings, then reduced into main three themes, and lastly abstracted to generate six sub-themes and more detailed categories. This analysis process was done separately for F14 and W15. Finally the reporting phase involved, as it intuitively sounds, reporting on the findings.

FINDINGS

Engineering Leadership Definition: Quantitative Summary

All of the definitions provided by the participants were transcribed for review. Quantitative data is shown in Table 2, including the range in definition length, as described by the number of words, and the range in the amount of content included in each definition, as described by the number of codes.

It is notable that from F14 to W15, the definitions not only increased in length and content, but also decreased in the amount of variability. During the F14 conference, there were participants with minimal leadership experience, as well as some with extensive leadership experience. This could explain the higher variation as the participants with extensive experience would have been able to provide a more detailed and complete definition of engineering leadership. Whereas during in W15, most of the participants had been involved in leadership activities in some capacity throughout the year.

Table 2. Summary of participants' definitions of engineering leadership.

		Fall 2014	Winter 2015
Number of definitions		28	26
Length (number of words)	Total	453	590
	Min.	2	10
	Max.	47	47
	Avg.	16.2	22.3
	St. Dev.	10.8	7.3
Content (number of codes)	Total	92	119
	Min.	1	2
	Max.	10	10
	Avg.	3.3	4.6
	St. Dev.	2.0	1.7

Engineering Leadership Definition: Qualitative Analysis

Using the qualitative content analysis each definition was broken down into codes, or its basic concepts. Similar codes were given headings, grouped together and three main themes were determined from the data: *Strong Character, Team Dynamics* and *Technical*. Table 2 lists these themes, as well as six sub-themes. Participants' definitions that particularly emphasized each sub-theme are given as an example.

Of the total codes from each conference, the proportional frequency of inclusion within each of the three themes was determined (Figure 1). Of the three themes, the first two are very general and could be applicable to a leader within any context. However, the third theme, *Technical*, is what truly differentiates a leader from an *engineering* leader. These technical skills are distinctive to the field of engineering, and it is good that the technical theme emerged from the students' definitions, showing that they also recognize its importance.

Table 2. Determined themes and sub-themes of the term *engineering leadership*.

Themes	Sub-Themes		Example Participant Definitions
Strong Character	Personal Character	F14	"Set an example through responsible, accountable, and ethical behaviour."
		W15	"Engineering is about innovation and breaking paradigms: a leader will take the first step."
	Influential Character	F14	"The ability to inspire trust and confidence in a group of people."
		W15	Help others "to unlock their skills and potential"
Team Dynamics	Team Leader	F14	"Manage people, projects."
		W15	"Make critical decisions for projects, even if not everyone agrees."
	Team Work	F14	Engineering leadership "is particularly important due to a group effort, […] know when to step up and allow for others to do the same"
		W15	"Instill interest in task to show people effect of participating in said task"
Technical	Skills	F14	"Problem-solving and communication."
		W15	"Exceptional time management, organizational and conflict-resolving skills"
	Problem Types	F14	"Tackle complex social, developmental, and global issues with confidence, courage, and humility."
		W15	"Bridging the gap between technical knowledge and effective solutions to engineering problems"

However, the largest change seen in the proportional frequencies in Figure 1 was a decrease in the inclusion of the *Technical* theme. This could be explained by the fact that the majority of the leadership opportunities available to students at the Schulich School of Engineering are extracurricular, including student clubs (e.g. Engineers Without Borders, Schulich Soundstage), competition teams (e.g. Solar Car, Formula SAE, Baja SAE), and associations (e.g. student governance). Although the competition teams have a technical component, the majority of the leadership activities in which engineering students participate are non-technical in nature.

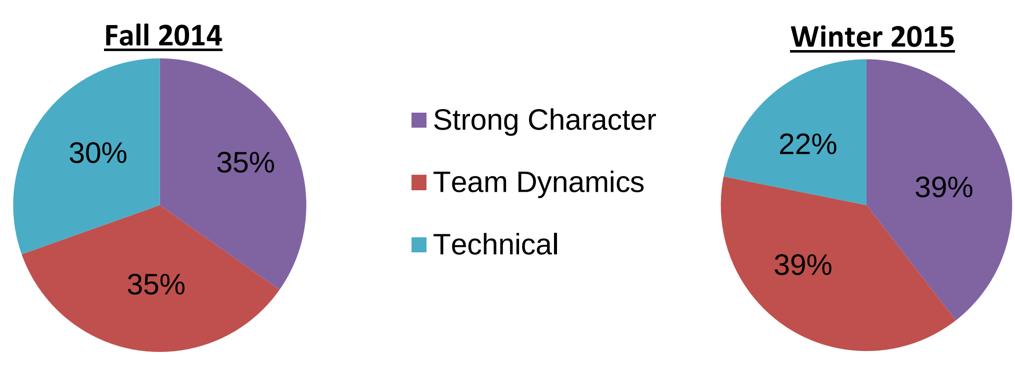

Figure 1. Proportional frequency of engineering leadership themes from the F14 conference (left) and the W15 conference (right).

At the beginning of the year the students understood the importance of the technical aspect of engineering leadership, however, at the end of the year, pulling from their own experience, they did not see as much value or need for engineering leaders to have technical competence. This supports research which has shown that the integration of professional skill development, such as leadership, helps students to better integrate their knowledge to solving complex problems (Karim et al., 2012; Litzinger et al., 2011; Martello & Stolk, 2007).

The CDIO Standard 3 Integrated Curriculum encourages the integration of professional skills into the curriculum, stating that there should be "an explicit plan to integrate personal and interpersonal skills, and product, process, and system building skills" (Crawley, Malmqvist, Östlund, Brodeur, & Edström 2014, p. 36). One of the best approaches to improve the integration of content is to provide instructors with training that gives them the ability to embed the professional skills within their technical course content (Teerijoki & Murdoch, 2014; CDIO Standard 9, 10). If instructors were provided with training on leadership skills, this would be a positive step towards improving students' perceptions of leadership.

After grouping the codes into the three main themes and six sub-themes, the data was abstracted to generate categories, with 14 categories from F14 and 16 categories from W15 (an overlap of six categories). A visualization summarizing all of the themes and categories is shown in Figure 2.

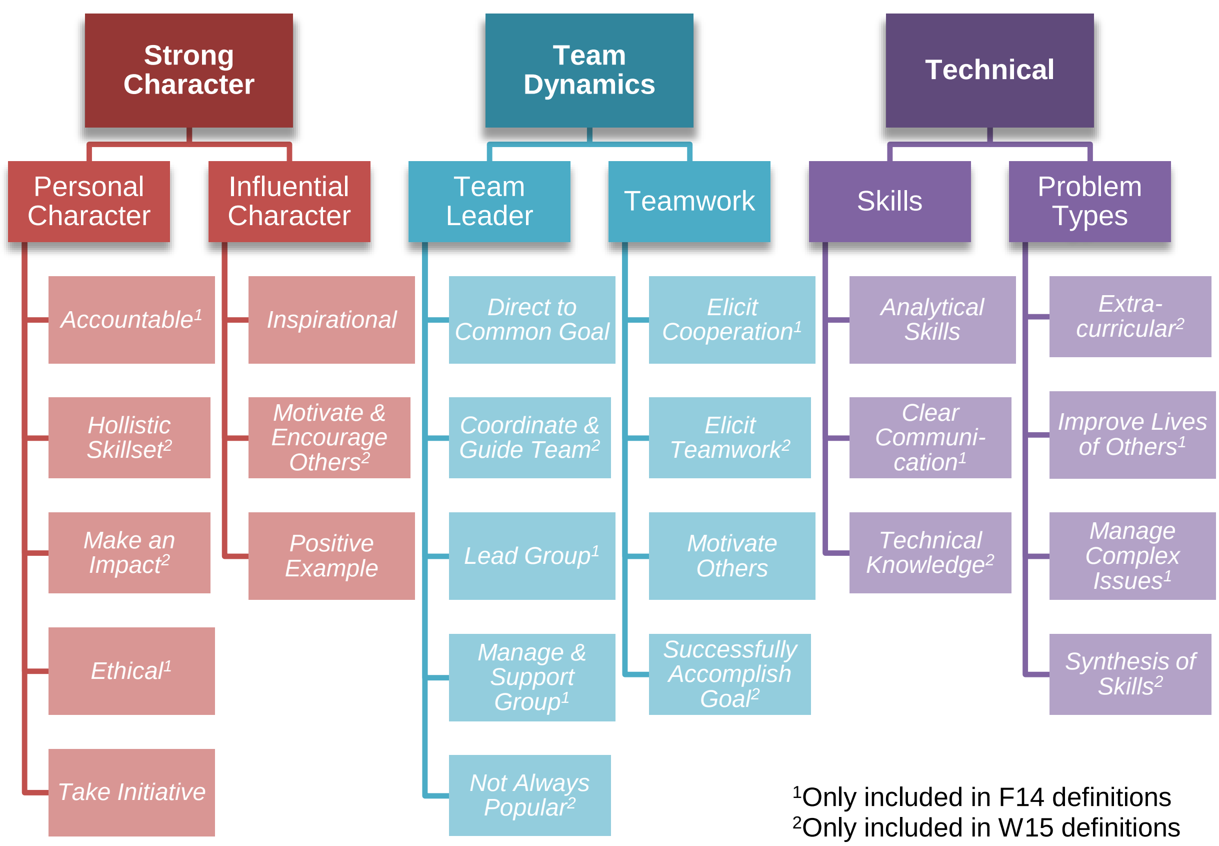

Figure 2. Visual representation of determined themes, sub-themes and categories of the term engineering leadership.

Although some of the categories seem quite similar, there was a slight difference in the language used by the students. For example, *Elicit Cooperation* from F14 compared to *Elicit Teamwork* from W15. In F14 definitions included terms such as “collaborate with group,” “working with others,” and “group effort.” Whereas in W15 the definitions included “lead interactions between teams,” and “it’s more about teamwork than about authority.” When the students were speaking from experience, they were able to provide more specific examples of what elements of leadership were really important to them, rather than what they thought would be important at the beginning of the semester.

The seven months of leadership experience from F14 to W15 provided notable differences in the students’ definitions of engineering leadership. Some of the preconceptions they held at the beginning of the semester were changed through their own personal leadership experience. However, even the most experienced student leaders do not have significant leadership experience. The results outlined above provide an overview of student preconceptions of leadership and should be used to understand the student’s perspective.

Engineering Leadership Definition: Comparison to Published Definitions

Definitions that were provided initially by well-known organizations covered many concepts, and specifically four general ideas that they expressed will be highlighted.

1. Take action – lead change (GEL), make decisions (NSPE), invention (GEL and CDIO)
2. Manage uncertainty (NSPE, CDIO)
3. Teamwork – team (NSPE), facilitate (CDIO)
4. Help others (CDIO), trust and loyalty (NSPE)

The latter two of these were well covered in the definitions provided by the students, however, the first two ideas were less prominent. The category *Take Initiative* relates to the idea of taking action however it more emphasized stepping up rather than getting things done. The concept of uncertainty could be indirectly related to the category *Manage Complex Issues,* however complexity and uncertainty are two very different concepts that must be managed within engineering projects.

Overall the students’ perspective of engineering leadership is appropriate, however there are some key elements lacking. Within the curriculum, it is essential to ensure students are able to learn and practice the full spectrum of engineering leadership, including conceiving, designing, implementing, and operating as leaders within an engineering context.

CONCLUSION

Engineering undergraduate students with an interest in leadership have an understanding of the term engineering leadership. A more complete and integrated engineering leadership experience would provide them with insight into an improved understanding. The themes and categories generated from the students’ definitions could also be used to develop and improve engineering leadership education programs

Students understood the importance of being technically competent as an engineering leader, however a lack of technical leadership experience caused the perceived value of technical competency to diminish. Providing students with integrated engineering leadership education experiences within the technical curriculum would allow leadership skills to be gained concurrently with an understanding how these skills apply to a technical engineering career.

Future Directions

The methods and results used in this pilot study will be applied to a variety of engineering populations including first-year students, fourth-year students, graduate students, professors and professionals. Gaining an understanding of each population's perspective will provide insight into what students think they need to know, what professors think they should teach and what is actually desired from industry. The data will also be analyzed in the different demographics, include the varied perspectives of females compared to males, and early-year students compared to later-year students.

The determined definition of engineering leadership and skills required to be a leader in engineering could be used to further investigate the importance placed on these elements. Many studies have shown that industry desires new graduates to possess engineering leadership skills (Hillmer, Wiedenbrueg, & Bunz, 2012), however if students and professors do not see a value in the skills, they will not be motivated either to learn or to teach them.

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BIOGRAPHICAL INFORMATION

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