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The Design and Implementation of Engineering Leadership Programs: A Comparative Study

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Abstract

Changing technological world requires future engineers not only show excellent technical skills, but also possess multiple skills and attributes, in particular leadership skills. Against this context, some universities and engineering colleges have developed pioneering engineering leadership programs to promote leadership among engineering students. This paper compares twenty-one engineering leadership programs around the world by analyzing the differences and similarities across these programs via text analysis. By exploring the outcomes and implementation of these engineering leadership programs, this paper found that visioning/setting goals, thinking or reasoning skills, interpersonal skills and ethics are the key attributes emphasized in these engineering programs. Lectures, field trips and practical experiences are the most common implementation platforms to develop engineering leadership. This paper aims to offer a comprehensive understanding of current practices and offer suggestions for designing similar engineering leadership programs in the future.

Introduction

Fast-paced technological transformation and innovation demands not only technical expertise from future engineers, but also multiple soft skills, in particular leadership [1]. Crumpton-Young indicated that engineering leadership is the influence and ability to lead other engineers and technical staff to design, create, innovate, implement and evaluate and assess services and products [2]. MIT-Gordon engineering leadership program describes engineering leadership as a set of capabilities and values that enable a person to accomplish a multi-disciplinary complex project by leading teams instead of functioning as an individual technical contributor. Engineering leadership is a process to encourage leaders and team members to achieve common goals that cannot be accomplished otherwise by working alone [3]. According to Nation Society of Professional Engineers, leadership consists of a number of capabilities which are crucial at a professional level to contribute to public health, safety and welfare [4]. In summary, engineering leadership is a set of integrative capabilities covering diverse aspects such as effective communication, active participation in teamwork and capabilities to influence others.

Considering the crucial role of engineering leaders in affecting change, leadership has become a new standard in cultivating future engineers. Engineers with leadership skills gain a competitive edge in labor market [5]. Engineering leadership is essential for shaping enterprise culture, optimizing the organizational structure and increasing productivity [6]. In addition, increased global cooperation and collaboration in industry calls for engineers with strong interpersonal communication skills, teamwork skills and an awareness of diverse culture [5]. Engineering leadership education has also effected on accelerating engineering students' professional development [7]. It is said that "an engineer is hired for her or his technical skills,

fired for poor people skills, and promoted for leadership and management skills" [8].

With increased importance of engineering leadership, new criteria are proposed for engineers. National Academy of Engineering published *The Engineer of 2020 - Visions of Engineering in the New Century*, which indicates that engineers in 2020 need to develop analytical skills, practical ingenuity, creative capability, communication skills, concepts of business and management, leadership, ethical standards and sense of professionalism [9]. The Royal Academy of Engineering in United Kingdom published *Educating the Engineers for the 21 Century - the Industry view*, highlighting future engineering graduates need to be equipped with creativity, innovation and leadership to lead the industry to succeed [10]. A Plan for Educating and Training Outstanding Engineers published by Chinese Ministry of Education proposed a list of competencies to be possessed by engineering undergraduates upon graduation, including good professional ethics, relating mathematics, natural science and economic management knowledge, basic engineering knowledge and skills, creativity and innovation skills, communication skills, organization and management skills, global vision and intercultural cooperation ability [4]. This plan requires that future engineers should not only become technical experts in their respective fields, but also need to be taking the leading role in the changing technological world by possessing multiple skills and attributes, in particular leadership skills. Engineer who possess leadership have the ability to lead an engineering team to create, design, develop, implement and evaluate products [5]. The development of an industry needs engineering talents who possess leadership ability. Engineering leadership plays a critical role in improving industry culture, optimizing the organization structure and increasing productivity [6].

Developing leadership has become an essential part for engineering students' skill development. Engineering students who are lack of leadership ability may encounter troubles in team activities during their professional career [7]. Universities and engineering colleges have assumed great responsibility for developing engineering students' leadership ability. Engineering leadership education programs have emerged in different universities in many countries. In this study, we compare twenty-one engineering leadership education programs in different countries by analyzing outcomes and implementation process. By so doing, we identify the similarities and differences of these programs.

Literature Review

It has been said that "an engineer is hired for her or his technical skills, fired for poor people skills, and promoted for leadership and management skills" [8]. Leadership development constitutes a critical aspect for engineers in industry. A survey data showed 77 percent of engineers indicated they played some leadership roles when they worked in an engineering team, and most of the engineers admitted that they lacked leadership and/or management skills [9]. Despite some efforts in launching engineering leadership programs, however, currently most current engineering schools still focus on students' technical skills with little attention on developing students' leadership or management skills [9] [10]. It is of great significance for universities and engineering colleges to develop leadership skills among

engineering students. Future effective engineers, especially engineering leaders must possess soft skills including written and oral communication, self-initiative, teamwork abilities, customer relations and decision making [5]. To achieve these skills, universities and engineering colleges, even industries should develop engineering leadership education programs to promote engineering students to develop leadership skills.

The programs of developing engineering leadership may have various forms. Some existing universities and engineering colleges which have already developed engineering leadership programs through co-operated courses, minors, integrated curriculum, scholarship programs, certificated courses and any other ways to help students acquire leadership knowledge and principle, team work skills, communication skills, creativity and innovation. MIT-Gordon engineering leadership program (ELP) is developed through cooperating with Sloan Business School, and it is an integrated curriculum to develop MIT engineering students' leadership ability [11]. The Engineering Leadership Development Minor (ELDM) of Peen State University is a minor program that engineering students complete this minor course through taking related leadership classes and obtaining the corresponding credits [12]. The engineering leadership program (ELP) in Iowa State University is structured in two phases to enable engineering student obtain eight established learning outcomes: in phase 1 (the first academic year), engineering students are devoted to community-building, and in phase 2 (rest of the academic year), engineering students are provided with an individualized program [13]. Royal Academy of Engineering in UK established Engineering Leadership Standard/Advanced Award programs in which engineering students are encouraged to participate in a series of outdoor activities for leadership training [14]. Considering the diverse formats and unique characteristics of different leadership programs, it is useful to conduct a thorough comparative study to understand the program outcomes, curriculum design and activities across the programs.

Methods

The study was conducted mainly by text analysis. Text materials related to each leadership program were collected mainly through websites of each program. Text analysis is a process which organizes and dissects qualitative data such as words, documents and forms [14]. Since the researchers themselves are research tools in qualitative research, text analysis mostly relies on the judgment and insight of researchers [15]. ATLAS.ti 7 was used as a tool to analyze text materials. In this study, we collected text materials of twenty-one engineering leadership programs from five countries, including U.S., Canada, U.K. and so on. Outcomes for different programs and their implementation processes were analyzed and compared across programs. Differences and similarities in the program outcomes and their formats of implementation were summarized based on the analyses.

Results

Program Outcome

Based on the text analysis, we found similarities and differences between engineering leadership programs. In terms of learning outcomes, most students developed professional skills, ability to adapt to the changing environment and gained international experiences either from exchange programs or internships in global enterprises. In other words, most engineering leadership programs actively incorporated leadership skills or attributes into in-class and out of class activities. We found that vision, thinking or reasoning skills, interdisciplinary knowledge, ethics were the most outstanding features of outcomes of engineering leadership programs. (Figure 1). Detailed descriptions and comparisons of outcomes across different programs are shown in Table 1.

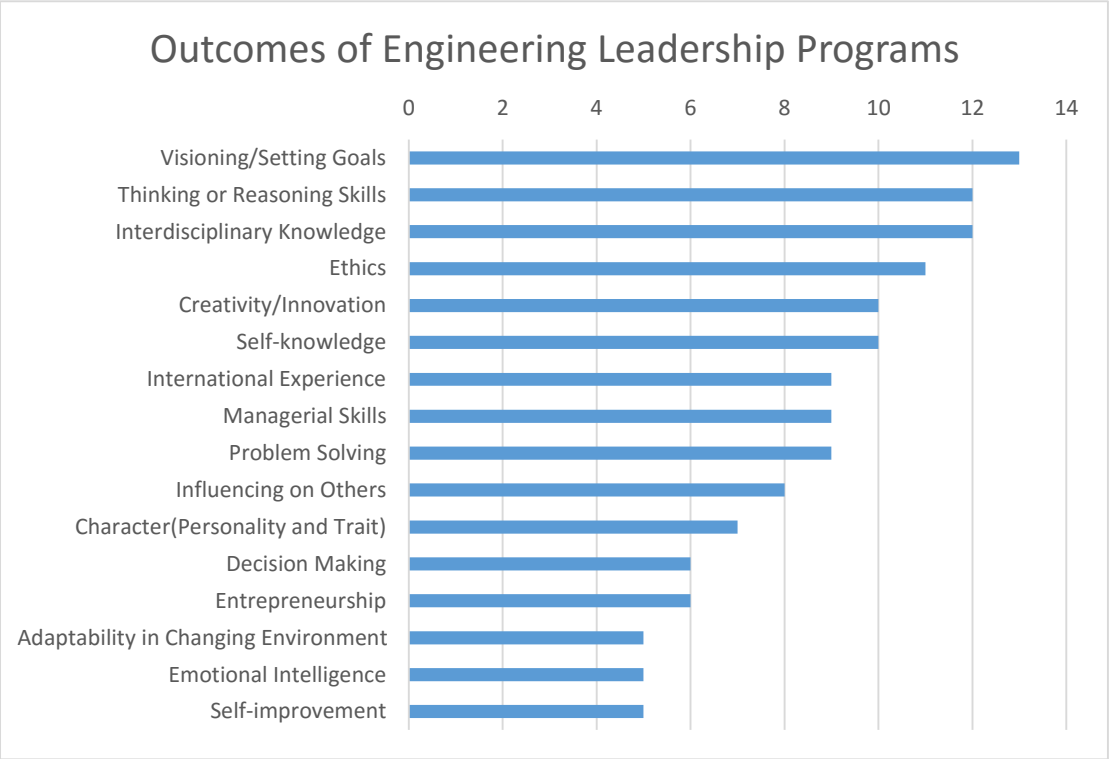

Figure 1 Outcomes defined in engineering leadership programs

Most programs paid special attention to helping engineering students develop communication/interpersonal skills and a teamwork spirit. As a result, curriculum design of engineering leadership programs aims to ensure graduates equipped with excellent communication skills to excel in their future careers. A number of programs laid emphasis on students' technical and professional excellences with regard to the learning outcomes. This is because engineering graduates who lack professional knowledge cannot become competent engineers, let alone engineering leaders. Some programs were oriented towards fostering students' vision and goal-setting skills which are vital for planning and decision-making as engineering leaders. Considering the importance of leadership foundation, many programs emphasized on students' leadership knowledge, including leadership concepts, theories and styles. Thinking or reasoning skills, such as logical reasoning, systematic thinking and analytical thinking skills, sharp observation, were highlighted by most programs. Interdisciplinary knowledge, including business, politics, law, economy and culture was also

one of the key areas for these universities and engineering colleges. Additionally, we found that most programs took self-knowledge, problem solving and managerial skills into account concerning outcomes of engineering leadership programs.

Figure 1 demonstrates a list of outcomes and their frequencies across different engineering leadership programs. We also conducted a close examination of detailed outcomes across these programs (Table 1). With a combination of Figure 1 and Table 1, we found that universities, including California University of San Diego, Cornell University and Toronto University, showed at least 10 main outcomes in terms of developing engineering leadership.

Considering the differences of these programs, as mentioned before, different programs presented unique aspects. Cornell University leadership program helped students develop time management skills by introducing timeline scheme. MIT leadership program highlighted the ability of sense-making, by which engineering students should learn to analyze concrete situation when implementing project tasks and problems. Five of these programs indicated the importance of macro-ethics, which refers engineers' training should take social accountability and take sustainability into consideration. Three engineering leadership programs from Iowa State University, MIT and Rensselaer Polytechnic Institute proposed the necessity for engineering leaders to have diverse perspectives. Special outcomes may also represent the unique strengths and features of these programs. It is essential to highlight the key features and unique strength for a new leadership program whiling referring to other existent engineering leadership programs.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
California University of San Diego			√					√	√	√	√		√	√	√			√	√	√
Cornell University	√	√	√	√	√	√		√	√	√	√		√	√	√	√	√	√	√	√
Iowa State University		√	√		√			√		√	√	√	√	√				√	√	√
Kansas State University			√				√	√			√			√					√	
Kyoto University				√						√	√				√			√	√	√
Lehigh University	√		√	√	√					√					√		√	√	√	
Loughborough University			√						√	√			√	√		√		√		
MIT		√	√	√	√		√	√		√				√	√	√	√	√	√	√
Monash University	√		√	√			√	√		√		√	√				√	√		
Ohio State University		√	√			√				√			√			√		√		
Penn State University			√	√			√	√			√	√					√	√	√	√
Purdue University			√	√				√	√		√								√	
Queensland University of Technology			√					√			√	√		√					√	
Rensselaer Polytechnic Institute	√		√		√	√			√			√	√		√		√	√	√	√
Rice University	√		√				√					√	√				√	√	√	√
Royal Academy of Engineering			√	√		√			√		√		√					√		√
Southern Methodist University		√	√							√			√		√			√		√
Toronto University		√			√	√	√		√	√	√		√	√			√	√		√

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
University of Central Florida			√	√					√			√	√		√		√	√	√	√
University of Colorado		√		√					√	√	√	√	√	√	√	√	√	√		
University of Michigan			√								√	√						√	√	√

Table 1 Outcomes for students as defined in the engineering leadership programs of different universities

1 Adaptability in changing environment; 2 Character (personality and trait); 3 Communication/Interpersonal skills; 4 Creativity/Innovation;5 Decision Making; 6 Emotional Intelligence; 7 Entrepreneurship; 8 Ethics; 9 Influencing on others; 10 Thinking or Reasoning skills; 11 Interdisciplinary Knowledge; 12 International Experience; 13 Leadership Knowledge; 14 Managerial Skills; 15 Problem Solving; 16 Self-improvement; 17 Self-knowledge; 18 Teamwork ; 19 Technical/Professional Excellence; 20 Visioning/Setting goals

Implementation

In order to facilitate the development of engineering students' leadership, universities and engineering colleges implemented a variety of methods. For example, capstone courses and practical projects were adopted to improve engineering students' ability of team building. Most programs conducted field trips, internships, business activities, workshops, lectures, seminars, forums and experiential programs to develop engineering leadership. A number of universities, such as California University of San Diego, Lehigh University and Monash University employed at least six different methods to conduct engineering leadership programs. Both commonalities and differences exist in the implementation of engineering leadership programs.

Many programs share some commonalities in their implementation. The first most common method to develop engineering leadership among most programs is still lecturing. Engineering students learnt leadership knowledge, interdisciplinary knowledge, engineering skills, leadership experience through lectures. Field trips (visiting industry and company, leadership journey and residential community) is the second most common method for developing engineering leadership. Through field trips, students learnt how to cooperate with team members to solve complex problems and obtained leadership and management skills. The third most common method is through practical experience, such as internships. When doing internships in enterprises, students often had opportunities to communicate with industrial specialists to gain real-world experiences. By experiential learning and practicing in an engineering environment, the goal for students is to develop problem-solving skills, communication skills, networking skills and gain knowledge in engineering and leadership.

Meanwhile, these programs also present different features in their implementation. MIT-Gordon engineering leadership program adopted a leadership model, that is, the Four-Capabilities Model, which consists of four key capabilities of future engineers, and used it as a theoretical guidance to develop students' leadership in MIT. Penn State University, University of Central Florida and Purdue University all developed engineering leadership minors for students. In addition, special sessions were arranged to develop specific skills among students. For example, to improve engineering students' management skills, Loughborough University leadership program offered a 4-day outdoor management course to cover essential fundamentals on management. Moreover, some professional activities were also organized for leadership development. For example, Rensselaer Polytechnic Institute leadership program hosted an annual one-day conference co-sponsored by industrial partners. The annual conference aimed to provide opportunities for engineering students to communicate with engineering professionals on vision, culture and value related to corporations. Cornell University leadership program had a special focus on women leaders. By offering students with courses related to gender diversity, it aimed to encourage female students to be engineering leaders.

	Business/ Entrepreneurship Program	Capstone Course	Case Study Analysis	Certification Course	Conference /Meeting/ Session	Lecture	Experiential Program	Field Activities	Group Activities	Mentoring/ Training	Practical Experience	Seminar
California University of San Diego			√			√	√			√	√	√
Cornell University				√		√	√	√	√		√	
Iowa State University		√		√		√		√			√	√
Kansas State University						√		√		√		
Kyoto University					√	√		√				√
Lehigh University			√			√	√	√		√	√	√
Loughborough University						√		√			√	
MIT						√		√	√		√	
Monash University					√	√		√	√	√	√	√
Ohio State University			√									√
Penn State University	√	√				√		√			√	√
Purdue University	√			√		√	√	√				√
Queensland University of Technology						√		√		√	√	
Rensselaer Polytechnic Institute					√	√		√		√		√
Royal Academy of Engineering						√		√	√		√	
Rice University				√		√		√			√	
Toronto University						√	√				√	√

	Business/ Entrepreneurship Program	Capstone Course	Case Study Analysis	Certification Course	Conference /Meeting/ Session	Course	Experiential Program	Field Activities	Group Activities	Mentoring/ Training	Practical Experience	Seminar
Southern Methodist University							√	√		√		√
University of Central Florida				√	√	√			√		√	√
University of Colorado						√				√	√	√
University of Michigan	√	√				√		√			√	√

Table 2 Comparison of implementation measures or platforms across engineering leadership programs of different universities.

Conclusion

This paper summarized the differences and similarities of twenty-one engineering leadership programs across five countries. It presents the main characteristics and trends of engineering leadership programs by comparing their outcomes and implementation. Most programs emphasize the development of students' interpersonal skills, communication skills, visioning, influencing on others, problem-solving skills, reasoning and thinking skills, ethics and so on in their program outcomes. Meanwhile, most programs adopt varied platforms in their implementation, including field trips, entrepreneurship program. By a survey of the outcomes and implementation of these different leadership programs, this paper provides an overview of current working programs for engineering leadership development. By so doing, it offers a comprehensive list of practices for designing similar engineering leadership programs in the future.

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