Achieving Excellence in Master of Engineering Education: A Case Study of National University of Defense Technology's Practice

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Abstract

The profound societal impacts of technological developments call for a drastic change in the education of engineering leadership. There are too many definitions and theories of leadership all over the world. However, only recently has the term engineering leadership been introduced and the exact definition is still in progress. The aim of this research project is to answer the following: from the perspective of academics and professionals, what is engineering leadership and what skills are required to be a leader in engineering? How curricular changes to achieve "excellence" with which is defined and measured. Being a leading institution of China's modern national defense technology, National University of Defense Technology (NUDT) has been playing an important role in engineering talents cultivation, defense technology research and military modernization in China, contributing significantly to China’s aerospace cause, such as manned space flight, as well as the cyberspace development, demonstrated by “Tianhe-2” supercomputer project which ranks as the first place in 2014 top 500 supercomputer ranking again. This paper first provides a summary of interviewed of 91 experts and professors who have got certain achievements in the engineering leadership field. The transcripts were analyzed using a constant comparative method to determine constructs related to engineering leadership. An exploratory factor analysis determined the common factors across the survey items. The mixed methods approach resulted in the creation of 22 survey items categorized into four factors: Character (Ability), Technical, Management and Cultural. After that, this paper studies a real case of NUDT’s Master of Engineering education with determined themes and established a matched curriculum system which could be used to develop and improve engineering leadership. Last, the paper showed prospects of follow-up development.

Introduction

Engineers with strong leadership skills are increasingly in demand due to the evolving environment and roles engineers have to perform in the workplace1. There is a need to educate engineers not just in physics and mathematics, but also in many nontechnical areas, including globalization, communication, and leadership[2]. Engineers are expected to have the skills to manage, influence, think critically, make decisions, and collaborate2.One of the difficulties in the field of engineering leadership education is the need to clearly define the term engineering leadership[3]. A more clearly understanding of this term and the establishment of curriculum system will help institutions to improve the quality of engineering leadership education.

This research’s aim is to determine from the perspective of academics and professionals who has extensive experience in the field of engineering education leadership, what is engineering leadership and what skills are required to be a leader in engineering? From the summary of the analysis we established the corresponding curriculum system. First of all, current engineering leadership research and definitions will be discussed.

Literature Review

Leadership is a highly desired trait among engineers according to the Engineer of 2020[4].The foundational philosophy of leadership development methodology is inspired by West Point's three C's: Character, Capacity, and Competence (the three C's) [5]. Due to the complex and specialized nature of engineering, it is important to gain an understanding of leadership specifically within an engineering context[6].Engineering leadership is often determined by an analysis of what leaders in engineering do[7].

In 2010, the National Society of Professional Engineers (NSPE) defined 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"[8] (p.1). The CDIO Syllabus defined engineering leadership as "the role of helping to organize effort, create vision, and facilitate the work of others" (p.68)[9]. It is clearly stated that leadership is not orthogonal to the remainder of the engineering curriculum, but rather there is an extensive amount of overlap between leadership skills and the other engineering skills[9]. More study operationalized leadership, change, and synthesis within the context of engineering education, it may help to define learning outcomes and competencies for engineering leadership programs[3,10].Some research grouped three main themes from the perspective of engineering students, academics, and professionals: Strong Character, Team Dynamics and Technical[11].

Many universities have developed engineering leadership programs. The Bernard M. Gordon-MIT Engineering Leadership Program (GEL) aims to develop next-generation technical leaders with the values, attitudes, and skills necessary to understand and address engineering problems[12].The University of Texas at El Paso (UTEP) which recognized the growing emphasis on leadership development in engineering, has established a new engineering discipline called Engineering Leadership (E-Lead)[13]. Purdue's Engineering Leadership Minor have started incorporating resources such as workshops and seminars to hone skills such as communication, teamwork, and leadership in their students[14].

Overall, these definitions and programs provide different viewpoints of engineering leadership. Yet an accepted operational definition of engineering leadership, particularly among engineering postgraduates, is lacking, and in particular the lack of suitable curriculum system. For this reason, we solicited operational definitions of leadership from 91 engineering professionals working in industry and academia through one-on-one interviews and translated these responses into survey items. After that, we made new definitions and established with the adaptation of the curriculum system.

Population Surveyed

Surveys for the pilot study were distributed at a high-level engineering leadership training course, which was held at the Continuing Education College in NUDT in spring of 2013 and fall of 2013. Of the 91 training participants, 84 participants returned the questionnaire and completed the full survey. This was an acceptable number of participants in order to analyze the data since for qualitative inquiry and research John Creswell recommends about 30 participants[15].

We began the interview process by asking participants about their education, current positions, experience as leaders, and their self-perceived leadership style(s). According to their Self-reported leadership style，a high percentage of the participants (about 89.9%) has excellent leadership in academic settings. Examples of their accomplishments included serving as a chair of a technical committee in domestic largest professional associations, serving as a reviewer for multiple government agencies, dean of college in famous university, and being recognized for development programs with global impact. A summary of the participant Education Background and Research Field Distribution demographics can be seen in Table 1.

		Number of People	**Proportion**
Obtained Degrees	Doctorate	56	66.7%
	Master	23	27.3%
	Bachelor	5	6.0%
Professional Fields	Field of mechanism	22	24.2%
	Field of computer science, communication and electronic technology	30	33.0%
	Field of medicine and health	15	16.5%
	Field of materials science and technology	5	5.5%
	Field of civil engineering and surveying and mapping engineering	6	6.6%
	Field of environment, weather and textile	5	5.5%
	Field of fundamental science, philosophy, and social science	7	8.8%

Table 1. Education Background and Research Field Distribution of Experts and Professors

Through further analysis on the posts of 84 experts and professors, we found that all of them have the experience in cultivating engineering postgraduates, which not only guaranteed that they have relevant understanding and professional background to the cultivation of engineering postgraduates, but also guaranteed the pertinence of formulating cultivating plans in the next step.

Method and Results

We used a mixed methods study to explore the operationalization of leadership, according to Creswell and Plano Clark suggested using such an approach in cases where there are a limited number of studies and theories to guide research[16]. From the mixed methods approaches, we selected a two phase sequential design. The first phase was a qualitative study and the second phase was a quantitative. In the study's first phase, 91 engineering professionals answered interview questions about engineering leadership and 84 engineering professionals finished survey. In the second phase, constructs identified in the interviews were translated to survey items that were then grouped into factors representing leadership. The following sections describe in detail the data collection and analysis approaches for both phases of the research.

Phase I: Identifying Definition of Engineering Leadership.

We used a 31-item interview survey protocol, the participants were asked about their opinions about abilities of leadership. To clarify the concepts and define these abilities operationally, interviewees were asked to describe a definition and to provide the importance of each ability with respect to their professional lives, and give some examples in which they had encountered each ability. For Example, "How do you define Engineering leadership in general and what special qualities you think the engineering shall enhance?" .One part of the survey was designed with open-ended Question. This style of question was chosen in order to give the participants flexibility in their answers. The other part of the survey was designed with Single Item Choice Question. The participants were instructed to read each item and to indicate their agreement/disagreement on a five point Likert type scale (1=Strongly Oppose,2=Don't agree,3=Neither agree nor disagree,4=Agree,5=Strongly Agree). A constant comparative method was used to understand and analyze the views of the participants, which was selected as a coding and analysis process because it generates theory systematically and compares the meaning of indicators with one another to build a concept and its properties[17]. We used this method to finish the coding process to confront similarities, differences, and degrees of consistency of meaning across codes, categories, and constructs. First, we checked all of the transcripts carefully and wrote down any important ideas or notes. It is valuable to understand the overall views of the interviewers. Second, we coded the phrase or an idea as a self-contained unit and generated labels to reflect its initial meaning. Third, we identified relationships among labels and generated categories. These categories were constantly compared to other categories, with the goal of grounding the categories in the data. We constantly compared responses for similarities and differences and asked questions: What is going on here? What category or what property of category does this incident indicate? What is actually happening in the data[17]? In the fourth phase of analysis, relationships between the categories were examined and then collapsed under a construct (higher-level category) that explained most of the variation in the data[3].

The above steps led to the development of codebooks for Character, Technical, Management, and Societal. The Character codebook included many of the intrapersonal attributes, such as visionary, proactive, integrity, responsibility, outcome driven and fairness. For example, the engineers shall enhance included “visionary” (having unique ability and sometimes unconventional ideas to achieve a goal at the scientific frontier), “Proactive” (the ability to process data and make decisions based on available data within an environment), “Integrity” (The ability of systematically integrating the innovative factors in the engineering field). Overall, the percentage of interviewers thought that these three Character should be owned respectively is 91.67%, 60.71% and 58.33%. Besides, interviewers who thought that the leadership also includes responsibility, outcome driven and fairness separately count for 2.38%, 2.38%, and 1.20%. Moreover, about 50% of interviewers thought that the visionary is a challenge to the quality of engineering personnel in the age of Big Data. This challenge mainly embodies as the ability of analyzing and judging the engineering value contained in a great capacity of scientific and technological information. Many think that the bottleneck of engineers doesn’t lack in the shortage of information collection ability, but lies in the lack of ability in information processing, analysis and judgment.

The Management codebook included various types of management. First, project management, such as management in economy, social, and global world issues, are included. Around the world, from "Manhattan" project in the United States to the “Manned Spaceflight” project in China, the large-scale scientific and technical projects are famous for intensive scientific and technological resources, large engineering scale, numerous participants, and profound social impact. 56% of interviewers thought large project is very important on enhancing the engineering leadership training. However, 34% of interviewers pointed out that this method was against the interest-oriented high-level engineers’ principle. Second, team management, the importance of being able to organize and lead the team with different layers and levels. Finally, Technical management, constructs related to the skills needed for managing technical changes, such as being flexible and having multidisciplinary skills in basic technology and application technology, were covered.

The Societal codebook included many of the condition aspects and societal issues in engineering. Constructs included "scholarly" atmosphere, respect principles, interactive communication and business elements during the engineering process. Relationships between engineering and social responsibility, politics, ethics, and global issues were identified as societal issues. According to the data of survey, 65% of interviewers selected "scholarly" atmosphere and only 8% selected the hardware condition among societal issues. Survey data shows that the interactive communication is the main method to cultivate the leadership in the engineering field. 85% of interviewers thought professor and students should try hard to tackle engineering challenges together. Partial experts think that the point-to-point communication and cooperation in the engineering practice surpass the scope of pure knowledge teaching and it more reflects inheritances of scientific idea and scientific taste.

Through a series of discussion, we continuously improved the construct definitions that verified each construct throughout research. We conducted interceder agreement checks to determine whether the same constructs (or different ones) were selected[18]. In the fifth phase of the analysis, we categorized the findings into four themes that incorporated. We reviewed the themes to determine how they might contribute to an overall Understanding, and whether they offer new insights into the interpretation of engineering leadership. We determined that the four themes adequately reflected the responses provided by participants. Table 2 lists these themes and sub-themes.

Themes	Sub-Themes	Definitions Explain
Ability	Visionary	having unique ability and sometimes unconventional ideas to achieve a goal at the scientific frontier
	Integrity	The ability of systematically integrating the innovative factors in the engineering field
	Proactive	the ability to process data and make decisions based on available data within an environment
Technical	Utilization of technology	The ability of ingeniously combining the scientific theory and engineering technology
	Practice ability	The ability of utilizing technology to solve the actual engineering difficulties
Management	Team Management	Organize and lead the team with different layers and levels
	Project Management	Finish a specific project and practice
	Technical Management	Leadership in basic technology and application technology
Culture	"scholarly" atmosphere	Respect principles, advocate science, encourage innovative value orientation, and with a scientific research atmosphere that students don't blindly follow others
	Mentoring effect	Mechanism of bi-directional function between the great teacher and the outstanding students, and two-way guidance for learning
	Interactive communication	Surround the interested topic and independent research direction to carry out equal and even heated discussion

Table 2 Determined themes and sub-themes of the Engineering Leadership Model

After the model of Engineering Leadership which includes ability, technology, management and culture were established, we organized to discuss and analyze the proportion of them. At last, according to the survey, the proportion distribution of each factor was obtained.

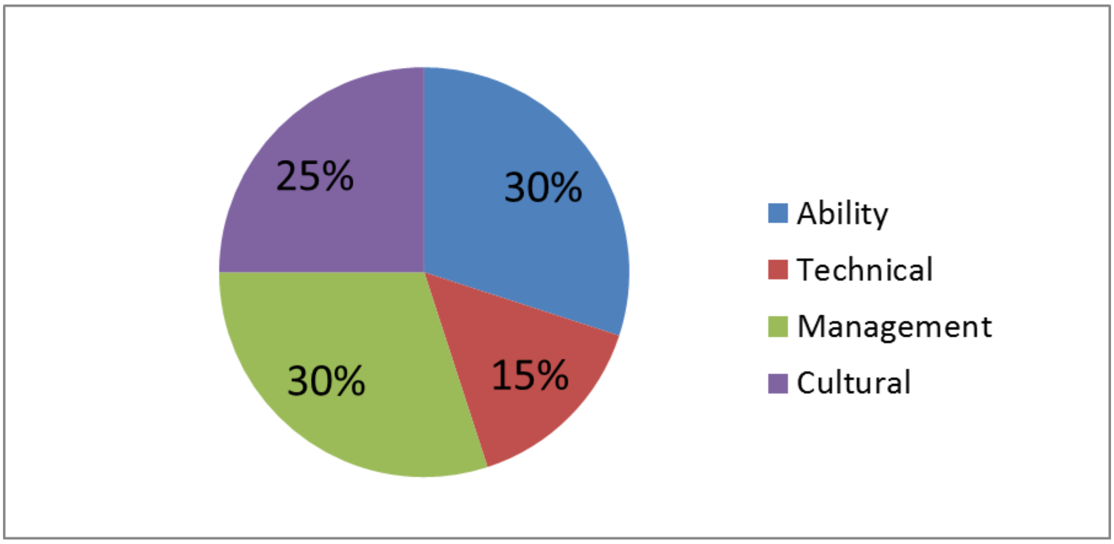

Figure 2. Composition of engineering leadership themes.

Phase II: Establish the corresponding curriculum system in NUDT University

In the following, the cultivation of engineering masters in the control engineering field in NUDT University was analyzed and established the corresponding curriculum system based on previous definition of Engineering Leadership.

1. The Analysis of Original Curriculum System and its Features

According the 2005 National Engineering Education conference, educational needs and rules of cultivating engineering postgraduates in the control engineering filed was formed, and the postgraduates' knowledge structure in the control engineering field should be as follows[19]:

- The knowledge structure that is centered on control theory, system theory and information theory;
- The relevant knowledge about specific direction of application, which is combined with mathematical method, computer technology, network technology, communication technology, various sensors and actuators, etc.
- The instrumental knowledge including the common used system and application software in the industry, etc.
- The knowledge of humanities, certain attainments in humanistic spirit, philosophical thinking ability, and the knowledge that can be used to guide the engineering practice[20].

The Education Program is composed of three types of curriculum modules, public major's courses, specialized courses and optional courses. The public major's courses include mathematical basic course, foreign language, natural dialectics and introduction to engineering, etc. The specialized courses covered all research directions in control engineering filed, which include robot control, autonomous navigation technology, precise guidance and control, optimal control, system engineering, system simulation, etc. The optional courses include computer network, mechanical design, sensor technology, photoelectric technology, etc.

Despite the curriculum system for engineering master's training plays an important role, but for engineering leadership training is clearly insufficient. In this paper, we analyzed the current curriculum system based on previous definition of Engineering Leadership, which from four respects: ability factor, technical factor, management factor and culture factor as follows.

（1）Aspect of ability factor. The current curriculum system attaches importance to the knowledge structure of students, but it lacks relevant contents about the development trend and the application of the world science and technology. It is difficult for students to understand the direction and emphasis of the future development of in the control engineering field. Because of the insufficiency of visionary, proactive, integrity, they may unable to see through the engineering application prospect to achieve a goal at the scientific frontier, and lose ability of systematically integrating the innovative factors in a great capacity of scientific and technological information.

（2）Aspect of Technical Factor. The current curriculum system plays a good supporting role in the aspects of writing technical reports or academic papers, obtaining domestic and foreign literatures, and cultivating writing skills, but its supporting function to the skill of using relevant R&D tools is insufficient, especially the application courses for engineering practice is not sufficient, which makes that the scientific theory and engineering application can’t be effectively connected with each other in the research, and the postgraduates can’t utilize technology to solve the actual engineering difficulties. Thus, it is hard to satisfy the requirements of cultivating the practice ability, engineering application ability and occupational quality of postgraduates.

（3）Aspect of Management Factor. The current curriculum system puts particular emphasis on the cultivation of academic theoretical level and study ability, but it lacks case curriculum and comprehensive project management course, which is against the team management and engineering management training, and is against cultivating the abilities of independently working on engineering design and operation, analysis and integration, management and decision making.

（4）Aspect of Cultural Factor. At present, the university generally pays attention to the construction of hardware conditions, “scholarly" atmosphere and interactive communication are inadequate between professors and students. Teacher-Center is still a common phenomenon. The investment in teaching is relatively insufficient; especially the interaction between professors and students is less. The mentoring effect lacks standards due to difficult in quantification.

2． The adjustment of curriculum system

In order to cultivate engineering masters in the control engineering field and improve the Engineering Leadership quality of postgraduates, under the guidance of *Professional Degree Standard for Engineering Masters in the Control Engineering Field*, we established new curriculum system with the requirements of new definitions. Table 3 lists new curriculum system and main content of the courses.

Subject	Main content of the courses
Subject One: Courses on Ability	
Topic1: The logic of scientific discovery	Learn basic theory of scientific discovery, understanding the theory of achievement and its applications, application of scientific methodology in the practice of scientific and technological innovation
Topic2: Philosophical thinking and engineering leadership training	Learn Philosophical theories, methods and applications, philosophical theories, methods of thinking in engineering application of leadership development
Topic3: Theory, methods and applications of technological innovation	Learn basic theory and latest development of technological innovation, Discussion on technological innovation in engineering applications; Study on technology innovation approaches and methods
Subject Two: Courses on technical	
Topic1: Basic science research innovation and experience	Pushing forward the initiative innovations in engineering area with studying characters and holding trends, building an innovation team to carry out scientific research and lead the international forefront of innovative practice.
Topic2: Development and application of control engineering	Understand the current situation and development trend of control engineering technology both at home and abroad. Grasping the needs of control engineering scientific and technological innovation, study control engineering and technology in national development strategies.
Topic3: Science and Technology Development Strategies in engineering leadership	Focus on the learning about the development trend and application of the engineering leadership of the world, the development history, policies and strategic planning of China’s science and technology, understand the focus of innovation and research in engineering leadership fields.

Subject Three: Courses on Management	
Topic1: Practice and Thinking on major Engineering projects- A Case Study on “Tian-He supercomputer”	Learn and communicate about the cross-disciplinary organization and management system in the major scientific and technological project “Tian-He supercomputer”, Tian-He’s team culture and the experience in the construction of system quality management and other aspects.
Topic2: Key Technology Breakthrough and Inspiration of Major National Projects	Focus on tackling key engineering technologies in aerospace, electronics, compute, etc., and learn and communicate about the experience in engineering innovative practice and making breakthrough in core technologies.
Topic3: Innovation in engineering practice and team-building	Exchange and Master Direction of Innovation, thinking of leading the frontier, Study leading the team to develop key technology research as a leading role.
Subject Four: Courses on Cultural	
Topic1: Strategies and Policies of National Scientific and technological Innovation	Understand national medium and long-term science and technology development plans, innovation-driven development strategies, national science and technology innovation system construction and its policies and measures, etc.
Topic2: culture of innovation and engineering leadership	Study history, present situation and development trend of University cultural construction, Analysis of the innovation culture and the important role of engineering leadership development, Thinking about University culture and development countermeasures.

Table 3. New curriculum system and main content of the courses.

Conclusion

Engineering Professionals have a reasonable understanding of the term engineering leadership. A more complete and contextual engineering leadership experience would provide them with insight into an improved understanding. The results from the themes and categories generated from the Engineering professionals’ definitions would be useful in developing and improving engineering leadership education programs.

According to the analysis done in the paper and in the application of curriculum design for the cultivation of engineering masters in the control engineering, the case shows that the thought of experts and professors, in the engineering field, treating courses as the key points and the engineering practice as the goal to cultivate engineering masters is very clear, and they have personal experience about the shortage in the current engineering master cultivating system.

Providing students with integrated engineering leadership experiences directly within the technical curriculum would allow the necessary leadership skills to be gained. Concurrently with an understanding how these skills will apply to an engineering career.

Future Directions

The methods and results used in this pilot study will be applied to a variety of engineering including aerospace engineering, and other engineering fields.

According to the thought put forward in the paper, however, as the viewing angles among school, industrial circle and students are different and there is a difference of understanding in the different countries, thus there are also different understandings about how to cultivate the leadership of engineering masters. In the later research and survey, it is suggested to enrich the current four-factor module based on the scientific research, and constantly exploit the international vision of cultivating postgraduates and improve the leadership, and create a higher-level international cultivating platform for the engineering education by combining with the actual construction practice of course.

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