Developing Engineering Leaders for the 21st Century

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***Abstract*— In today's fast pace and change-driven environment, it has become ever more critical for organizations to recognize that many of their engineers - at some point in their careers - will have to take over leadership roles. Engineers are no longer only involved with the technical project details but must also understand the broader picture as they are often acting as team leaders and are expected to improve the lives of others and help society. Their organizations understand there is a need to educate engineers not just in physics and mathematics, but also in many nontechnical areas - including *leadership*. This paper describes the *Engineering Leadership Program* at Beihang University in China, which is aligned with world-class initiatives such as the Gordon Institute of Engineering Leadership programs at MIT and Northeastern University in the United States. The paper describes the motivation to establish the program, student learning outcomes and the elements, courses and learning activities as well as the assessment strategy to measure student competencies and satisfaction with the Program. Outcomes of the first course in the Program offered the Summer of 2018 are also included.**

Keywords—engineering leadership; professional skills; leadership; engineering education

I. INTRODUCTION

Beihang University School of General Engineering (SGE) started in 2016 as an "International Model School" within the "Propulsion Project for an International Model School of Higher Education" established by the State Administration of Foreign Expert Affairs and the Ministry of Education of China. The School aspires to be a "Double First-Rated" program (world class university, world class in the disciplines) and bring about a comprehensive reform to Beihang University and higher education in China. Two undergraduate programs, Mechanical Engineering and Aerospace Engineering were launched in 2017. The core courses of the programs are taught in English. The faculty of SGE includes long-term faculty and short-term visiting professors from all over the world, national distinguished specially-invited experts of China's so called "Thousand Talents Plan," who have worked for Beihang University, and professors responsible for the core curriculum of the related schools. SGE carries out the "Partner University Plan," which utilizes the "1→n" model [one with many] to cooperate with world top universities from around the world in research cooperation, curriculum building as well as professor faculty and student exchange programs.

SGE objectives are to:

- Facilitate the implementation of the SGE programs based on the mission and goals of the Beihang University.
- Maintain high standards in SGE education through excellence in teaching, research, and relevance of the curriculum.
- Attract and enroll top ranking students, nationally and internationally, who are motivated and enthusiastic about the multidisciplinary world-class SGE programs.
- Provide students with a high-quality experience through contact with faculty members, industry leaders, and through various national and global societies and professional associations.

- Communicate widely the success of the SGE program outcomes with the community, industry, profession, and related relevant technical societies.
- Provide a welcoming, stimulating, and dynamic work and learning environment for all.

SGE's programs have the following mission: To immerse individuals in an enhanced active learning environment to cultivate multidisciplinary educated aerospace and mechanical engineers who balance theory with applied science and engineering for advancing knowledge, problem solving, design, communication, leadership, and serving to serve the profession and society in China and globally. The Schools curricula were designed backwards, as an outcomes-based curriculum [1].

Figure 1 shows the SGE's curriculum model and learning experiences.

Students graduating from SGE are expected to demonstrate I^4L general competencies:

- **International**: Be able to address local, national and global engineering challenges and opportunities they will face in their careers.
- **Integration:** Contribute and provide quality service to the profession, the community, and the environment.
- **Leadership:** Be adaptive leaders that work and communicate effectively in complex and multidisciplinary environments.
- **Interdisciplinary:** Apply existing and innovative engineering technologies to solve real-life interdisciplinary problems.
- **Innovation:** Be creative and innovative, converting original ideas into reality, with high impact.

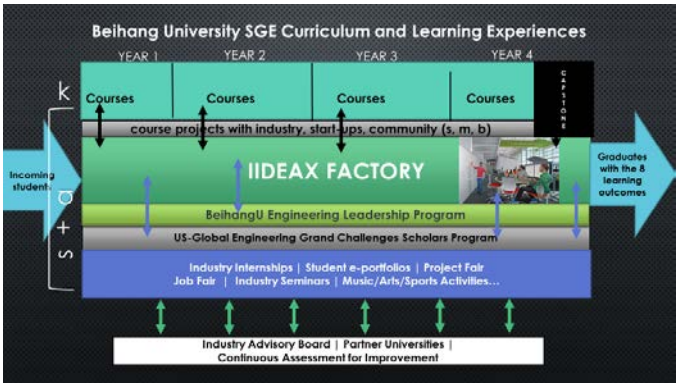


FIGURE 1. BEIHANG UNIVERSITY CURRICULUM MODEL AND LEARNING EXPERIENCES

Graduating students will also demonstrate the following eight (8) engineering specific learning outcomes (aligned with ABET new criteria and CEAB criteria) [2, 3]:

1. Knowledge Base for Engineering & Problem analysis
2. Use of Engineering Tools
3. Design, Economy and Project Management
4. Individual and Teamwork
5. Communication Skills
6. Life-long learning
7. Ethics, Equity, Professionalism and Impact of Engineering on Society and Environment
8. Investigation

Once the competencies and learning outcomes were established, benchmarks on world-class curricula were investigated. This exercise led to curriculum content to be reduced in number of credits and new learning experiences designed. Key elements of the program, as shown in Figure 1 include problem/project-based learning, a complex and vertically integrated major project (like the ones related to the Global Challenges Scholars Program), IIDEAX (a learning space for teamwork, creativity and innovation), and the ***Engineering Leadership Program,*** described in this paper.

II. THE ENGINEERING LEADERSHIP PROGRAM (ELP)

A. Motivation

The first responsibility of a leader is to define reality. The last is to say thank you. In between, the leader is a servant.
—Max DePree

In today's fast pace and change-driven environment, it has become ever more critical for organizations to recognize that many of their engineers - at some point in their careers - will have to take over leadership roles. Engineers are no longer only involved with the technical project details but must also understand the broader picture as they are often acting as team leaders and are expected to improve the lives of others and help society.

Recognizing the importance of equipping engineering students with leadership tools, SGE determined that a unique characteristic of its program would be providing its student with engineering leadership capabilities. This decision was aligned with world-class initiatives such as the Gordon Institute of Engineering Leadership (GEL) programs at MIT [4] and Northeastern University [5] in the United States. Indeed, many elements of those programs have been adopted in X's Engineering Leadership Program (ELP).

B. ELP Objectives and Student Learning Outcomes

The program's goal is to "*Develop leadership skills and attitudes in engineering students.*" By skills we mean: abilities, strengths, competencies. By attitudes we mean: beliefs, values, feelings and dispositions to act in certain ways. The expected students learning outcomes include:

- Exhibit high moral, professional and ethical conduct
- Possess systems thinking skills
- Demonstrate creativity, innovation and entrepreneurial skills
- Possess project management skills
- Exhibit critical and strategic thinking skills

- Exhibit complex problem-solving skills
- Possess emotional intelligence skills
- Possess communication skills
- Demonstrate flexibility, adaptability, and multicultural sensibility
- Demonstrate quality decision-making skills

Again, the ELP was design with a backwards approach stemming from the student learning outcomes.

C. ELP Approach

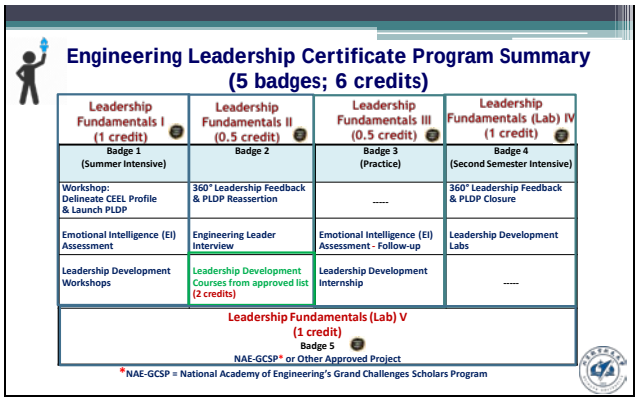
SGE ELP blends Engineering Leadership Concepts and Theory, Engineering Scenario Practice, and, Reflection and Values Development. ELP underlines the importance of contextual leadership experience and integrated learning experiences (the practice of leadership in the context of the engineering practice) with self-assessments and reflections for leadership planning and growth. Therefore, the ELP integrates a major project experience (like the Engineering Global Challenges or any other major project experience), engineering leadership "shadowing" and SGE existing courses.

The Program integrates the following general learning and development activities:

- **Continuous Assessment** – initial, formative and summative assessments by students (self-assessment), faculty and sponsors,
- **Engineering Leadership Foundations Curriculum** – 4 credit units in selected leadership and project topics. Students will be able to apply new skills and knowledge into their projects. Teaching methods for these courses include: face to face lectures, flipped (or inverted) learning, workshops, and other active learning methodologies. Two (2) additional elective credits chosen from SGE and Beihang University courses complement the curriculum.
- **Supplemental Leadership Development Activities** – to promote reflection and growth, together with experiential learning to expose students to real-life industry.

Table 1 shows the Program five (5) individual phases that spread over the four-year ELP Fundamentals program but that can also be taken at the student's convenience. For example, students may take a course each year per Table 1 or, if preferred, take more than one course per year. Nevertheless, given the scope and complexity of the project to be undertaken in Fundamentals V (Lab), this course may take more than a year to complete requirements. Each phase has credit value and upon completion of requirements, earns the students a "**badge**." In Leadership Fundamentals 1 through IV students are exposed to fundamentals of engineering leadership theory and they engage in carefully crafted group activities to develop, practice and home in their leadership skills in an engineering context, which is provided by Leadership Fundamentals V (major project lab).

TABLE 1. ENGINEERING LEADERSHIP PROGRAM PHASES



D. ELP Course Descriptions

Table 2 presents the ELP Fundamentals Courses' content and learning activities.

TABLE 2. ELP FUNDAMENTALS COURSES AND LEARNING ACTIVITIES

Course	Content	Learning Activities
Engineering Leadership Fundamentals I (1 credit)	• Leadership Competencies • Personal Leadership Development Plan • Emotional Intelligence • Leading New Teams • Motivating and Developing Others • Mastering Constructive Conflict • Discovering and Developing Your Leadership Strengths	Students work in teams and agree on the set of "Capabilities of Effective Engineering Leaders" (CEEL) upon which future leadership developmental activities will revolve around. Each student launches the "Personal Leadership Development Plan" (PLDP), a tool designed to foster personal development as students identify areas of focus and track growth as they practice leadership. Students take an "Emotional Intelligence" assessment. Four workshops on Leadership topics.
Engineering Leadership Fundamentals II (0.5 credit)	• 360° Leadership Assessment • Preparing for the Engineering Leader Interview • 2 electives in selected topics (2 credits)	360° Leadership Feedback (online tool) With 360° leadership feedback revisit PLDP and update Teams of students interview an engineering leader from industry, capturing lessons learned in a written report Electives: • Engineering Professional Ethics • Design Thinking • Engineering Innovation and Design • Project Engineering • The Art and Science of Negotiation • People and Organizations • Entrepreneurship
Engineering Leadership Fundamentals III (0.5 credit)	• Preparing for the Leadership Internship	Students procure and secure an internship and work to maximize their experience, seeking additional responsibilities or taking on a special project, gaining attendance to key strategic meetings not normally attended by interns, seeking relationships with key leaders within the company, building a network for their professional future, etc. They plan to deliberately practice some of the Capabilities of Effective Engineering Leaders
Engineering Leadership Fundamentals IV Lab (1 credit)	• Various leadership topics distributed throughout the semester (2-4 hours each, depending on topic) • 360° Leadership Feedback (online tool) • With 360° leadership feedback revisit PLDP and update	Through interactive role-playing, simulations, peer and self-assessments - led by instructor - teams of students explore topics via practical experience. Lab is performance-based, and students receive direct feedback at the end of each session. Sessions can be held both inside and outside the classroom.
Engineering Leadership Fundamentals V Lab (1 credit)	Topics vary depending on project selected	Engage in GCSP or similar approved long duration project where students can practice their leadership skills (teams) Annual Project Update and Presentation (team)

III. ELP AND THE GCSP

As seen in Tables 1 and 2, one important element of the ELP is the student's engagement in a major team project or research experience wherein they can practice, hone in their leadership skills and others can evaluate their leadership performance. In 2018, Beihang University became a member of the US National Academy of Engineering Global Challenges Scholars Program (GCSP) [6], becoming only the 2nd university in China to do so.

All SGE students will be required to participate either in this program (and fulfill its requirements to obtain the Scholars Certification from the US NAE) or any other major project or research endeavor.

IV. ELP OUTCOMES ASSESSMENT

Before you are a leader, success is all about growing yourself. When you become a leader, success is all about growing others. —Jack Welch

Learning outcomes assessment is an integral part of every outcomes-based accreditation system. SGE undergraduate programs have been designed to be able to comply with ABET accreditation criteria, thus the ELP student learning outcomes assessment strategy has been carefully designed and implemented. Student learning outcomes are assessed via direct assessments (i.e., courses' tasks deliverables) and indirect methods (surveys and focus groups). Direct and indirect assessments include:

- Personal Leadership Development Plan
- Emotional Intelligence test results
- 360^0 Leadership Feedback
- Engineering Leader Interview Report
- Major Project Mentor Evaluation
- Program Satisfaction Survey

Students also evaluate instructors, mentors, seminar speakers and their satisfaction with the courses, learning activities and Program.

V. OUTCOMES OF THE FIRST COURSE IN THE PROGRAM – SUMMER 2018

The first course in the SGE ELP, Engineering Leadership Fundamentals I, was offered in July 2018 to fifty (50) very enthusiastic SGE students (they had a preview of the course content and teaching/learning activities in the Spring semester). Figure 2 presents the ELP course intensive agenda, which was divided into two parts: 1) Engineering Leadership Seminar Program and 2) Workshops and Labs.

Leveraging an International Engineering Education Forum held at Beihang University prior to the ELP kick off, eight international speakers from academia and industry were invited to select a leadership competency and address the students in a two and a half days seminar program. Students were presented a rich and wide variety of leadership experiences on topics ranging from teamwork to vision, ethics, negotiation and decision making and from different perspectives: geographically (Canada, Chile, Europe, India, Puerto Rico, and USA) and backgrounds (academia and industry). Figure 3 shows a team of students having fun engaged in the teamwork and leadership seminar/workshop.

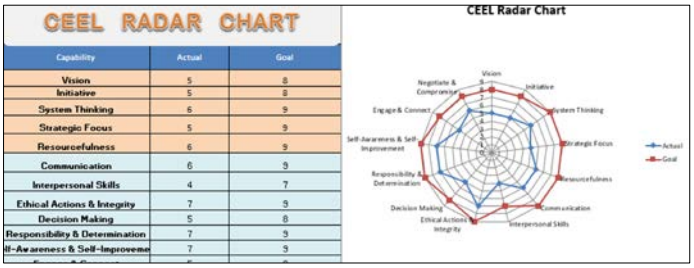
The second part was the offering of the following course's planned workshops and lab:

- Workshop 1: Competencies of Effective Engineers Leaders Profile & Launch Personal Leadership Development Plan (PLDP)
- Workshop 2: Emotional Intelligence Assessment
- Lab: EI Assessment, Facial Expression Quiz and Completing the PLDP
- Workshop 3: Leading New Teams
- Workshop 4: Motivating and Developing Others
- Workshop 5: Mastering Constructive Conflict
- Workshop 6: Discovering and Developing Your Leadership Strengths

FIGURE 2. FUNDAMENTALS OF ENGINEERING LEADERSHIP PROGRAM – SUMMER 2018

FIGURE 3. A TEAM OF STUDENTS DOING THE SPAGHETTI CHALLENGE IN THE TEAMWORK AND LEADERSHIP SEMINAR

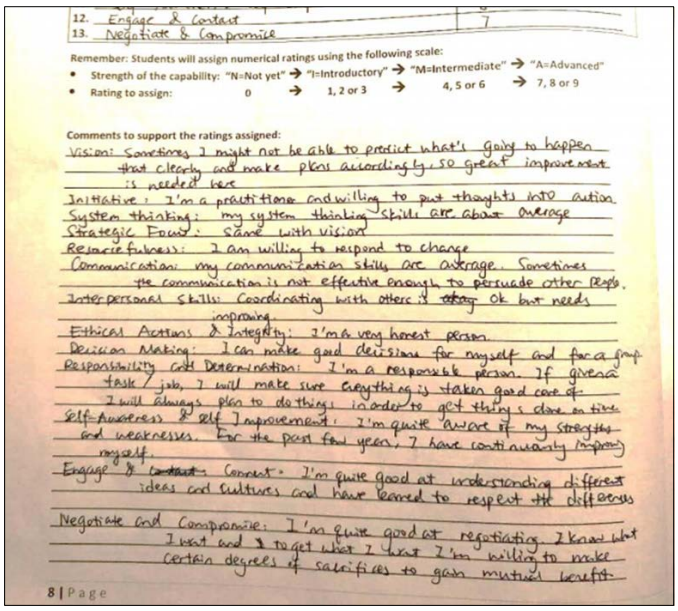
Some examples of student's work are shown in Figures 4 and 5.



CEEL RADAR CHART

Capability	Actual	Goal
Vision	5	8
Initiative	5	8
System Thinking	6	9
Strategic Focus	5	9
Resourcefulness	6	9
Communication	6	9
Interpersonal Skills	4	7
Ethical Actions & Integrity	7	9
Decision Making	5	8
Responsibility & Determination	7	9
ll-Awareness & Self-Improvem	7	9

FIGURE 4. COMPETENCIES OF EFFECTIVE ENGINEERING LEADERS: STUDENT SELF-ASSESSMENT AND GOALS



12. Engage & Contact
13. Negotiate & Compromise

Remember: Students will assign numerical ratings using the following scale:
- Strength of the capability: "N=Not yet" → "I=Introductory" → "M=Intermediate" → "A=Advanced"
- Rating to assign: 0 → 1, 2 or 3 → 4, 5 or 6 → 7, 8 or 9

Comments to support the ratings assigned:

Vision: Sometimes I might not be able to predict what's going to happen that clearly and make plans accordingly, so great improvement is needed here.
Initiative: I'm a practitioner and willing to put thoughts into action.
System thinking: my system thinking skills are about average.
Strategic Focus: Stand with vision.
Resourcefulness: I am willing to respond to change.
Communication: my communication skills are average. Sometimes the communication is not effective enough to persuade other people.
Interpersonal Skills: Coordinating with others is okay but needs improving.
Ethical Actions & Integrity: I'm a very honest person.
Decision Making: I can make good decisions for myself and for a group.
Responsibility and Determination: I'm a responsible person. If given a task / job, I will make sure everything is taken good care of. I will always plan to do things in order to get things done on time.
Self-Awareness & Self Improvement: I'm quite aware of my strengths and weaknesses. For the past few years, I have continuously improved myself.
Engage & Contact: Connect: I'm quite good at understanding different ideas and cultures and have learned to respect the differences.
Negotiate and Compromise: I'm quite good at negotiating. I know what I want and I to get what I want I'm willing to make certain degrees of sacrifices to gain mutual benefit.

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FIGURE 5. A STUDENT'S NOTES IN THE PERSONAL LEADERSHIP DEVELOPMENT PLAN

Finally, both parts of the course were evaluated by the students (n=36). Figures 6 and 7 show evaluations of the seminars by international speakers' program and the course's workshops and labs facilitated by the course professor.

FIGURE 6. STUDENTS' EVALUATION OF LEADERSHIP SEMINARS

Overall, results indicate that most students liked the experiences provided by both the international speakers and the instructor. They thought that speakers and instructor were knowledgeable in the topics presented, were clear in their presentations and provided for good teacher-student interaction. In addition, despite the language barrier (some of the students come from provinces and they are not very fluent in English), students were motivated and participated in the discussions. Most of the students (4.4/5.0) would recommend the ELP to other students and (4.2/5.0) hope to put into practice what they learned. Most of the comments made also indicate the value they found in the seminars and the diversity of speakers.

"I got a lot of experience on how to be a leader".

"A big thank you to the School of General Engineering and all of the professors and lecturers for this golden opportunity."

"I like it, especially the real experiences of the professors are very useful."

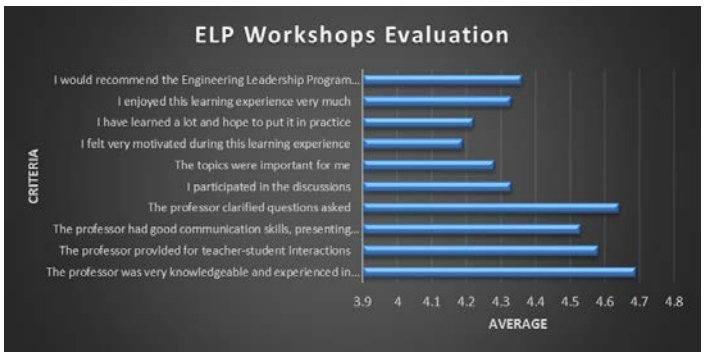

FIGURE 7. STUDENTS' EVALUATION OF LEADERSHIP WORKSHOPS

We also learned by students' comments and suggestions that they would like to have course spread over a longer period (not so intense) and have longer workshops (these were 2 hours long). This Summer there were time limits and scheduling issues that could not be resolved. Nevertheless, we hope to incorporate these and other recommendations in the future. Concerning content of the Leadership Seminars, students would like to see more case studies and focus on practical and applied learnings, not on theory.

"Excellent! Next time I hope we can have more time for the workshops!"

"…very excellent workshop! I love it!!! Please design more time for workshops! Thank you!!!!

As can be seen in Figure 8, students were satisfied and joyful in earning the first badge of the ELP.

FIGURE 8. ELP BADGE 1 GROUP PICTURE

VI. CONCLUSIONS

The Engineering Leadership Program designed by the School of General Engineering at Beihang University in Beijing, China consists of five (5) active and authentic learning courses distributed along the undergraduate curriculum. It aims at developing engineering leadership competencies (knowledge, skills and values) in all engineering undergraduates as part of a novel model school of engineering piloted by the government of China.

Outcomes results of the first course – Engineering Leadership Fundamentals I - appear to have satisfied the 50 student participants. Learnings from the first offering will be incorporated in the next offering of the course as well as in future courses in the sequence.

VII. REFERENCES

[1] L. Morell, Essentials to Innovate Engineering and Related Curricula, A must reference guide to navigate through a vital process, Mayagüez, PR: autopublished, 2017.

[2] "ABET," [Online]. Available: www.abet.org.

[3] "Engineers Canada Accreditation Board," [Online]. Available: https://engineerscanada.ca/accreditation/accreditation-board.

[4] "MIT Gordon Engineering Leadership Program," [Online]. Available: http://gelp.mit.edu/.

[5] "Northeastern University Gordon Leadership Institute," [Online]. Available: http://www.coe.neu.edu/orgs/gordonleadership.