

Turned from knowledge-based to innovation-based: Introduction of Emerging Engineering Education in China

Ying Li^{1,2}, Zhang Jiong¹, Tianyi Qi¹, Shicheng Yu¹

¹School of Computer Science and Engineering, Beihang University, Beijing, China

²Electrical Engineering, Princeton University, NJ, USA

Abstract—This Research to Practice WIP (Work In Progress) paper presents an innovative engineering education concept, Emerging Engineering Education. The fourth industrial revolution (Industry 4.0) has promoted the all-around transformation of education in engineering. To cope with the changes caused by Industry 4.0, the Ministry of education of China announced a new strategic guideline named "Emerging Engineering Education (3E)". The main purposes of 3E are: 1) proposing a new concept to establish an innovative, comprehensive and fully-cycled engineering education; 2) forming a new structure to combine the new and traditional engineering majors; 3) exploring a new model to cultivate the engineering technological talents; 4) developing a high-quality evaluation to improve international competitiveness of engineering education; 5) constructing a new system to strengthen engineering education. The main approaches to build 3E are inheritance and innovation, integration and emergence, coordination and sharing, which means to transform subject-oriented to industrial demand-oriented, transform subject independent to subject integrated, transform the role of adapting the requirements of application to the role of leading to the development of industry. This paper mainly focused on the innovation of 3E and discussed some methods of how to cultivate compound, creative and applied engineering talents.

Keywords—Emerging Engineering Education; Application Centered; Industry-University Cooperation; Engineering Talent

I. BACKGROUND OF 3E

Under the new situation of the development of knowledge economy, especially the emergence of the fourth industrial revolution (Industry 4.0), an unprecedented degree of interaction and cooperation has grown between engineering education and industry. The traditional higher engineering education cannot effectively meet the demands for current economic development. It is imperative to establish some emerging engineering disciplines by creating new technology or transform and upgrade some traditional engineering disciplines.

Therefore, "Emerging Engineering Education (3E)" has come into being. Furthermore, 3E is the outcome of the development of international higher engineering education. In the report of 2005, UNESCO said higher engineering education tended to "Diversification, informatization, internationalization".[1] To adapt to this change, many countries have advanced education reform. E.g., The United

States released a number of plans to strengthen engineering education including "2020 engineer plan", "Competitiveness plan" and "National action plan"; [2-4] European focused on the cultivation of engineering talents and established an integrated training system from undergraduate, masters and Ph.D. degrees; A global standard for Engineering education, "Washington agreement", was formulated by The United States, The United Kingdom and other 4 countries; [5][6] CDIO, a famous engineering education mode was proposed by Massachusetts Institute of Technology (MIT), and as early as the 1990s, MIT had put forward "big project", which emphasizes the close connection between engineering education and economic development. [7-9] From the scale of higher engineering education, the number of students trained in China accounts for a significant proportion in the world, as shown in Table 1. Therefore, the development of engineering education in China plays an important role in the research of international engineering education. [10][11]

How to cultivate the new engineering talents who can adapt to new technology, new industry and new economy is a huge challenge for educators all over the world. "Emerging Engineering Education" will provide a new perspective and a "Chinese Solution" for the development of international engineering education. [12][13]

Table 1 The scale of Higher Engineering Education

Country	Number of Students (Unit: Ten thousand)		
	Students in school	Enrollment	Graduates
China	1007.7	297.8	269.1
Russia	245.0	65.7	47.2
U.S.A	214.7		35.9
Brazil	129.8		
Korea	101.0	20.6	16.4
Mexico	94.9	25.4	13.9
Germany	72.8	20.7	12.1
Turkey	65.3	19.1	9.4
Japan	57.6	37.6	16.4
Spain	42.5		8.2
France	37.3		13.2
Italy	33.6		6.1
Britain	30.7	11.5	10.0
Canada	19.7		4.5
Australia	18.9		4.7

II. CONNOTATION OF 3E

3E is a new paradigm of engineering education with the characteristics of new concept, new structure, new model, new

evaluation and new system, which is proposed under the new economic conditions marked by new technology, new form, new model and new industry. 3E can be regarded as some new emerging engineering fields, disciplines or majors which are formed by the integration, intercrossing and expansion of science, applied science, engineering science and engineering practice.

3E includes three types, they are new pattern engineering (reform existing disciplines), newborn engineering (develop new interdisciplinary) and new emerging engineering (establish unprecedented disciplines). Specifically, 1) the new pattern engineering is formed by transformation, modification and upgrade of the existing or traditional engineering disciplines, which indicates the expansion of connotation, the improvement of training objectives and standards and the reform and innovation of training method; 2) The new born engineering is formed by the cross-combination between current engineering disciplines and traditional engineering disciplines and the interdisciplinary fusion between engineering and other disciplines; 3) The new emerging engineering is formed by the extension of other disciplines or the transformation of new technology and new industry.

III. CULTIVATING ENGINEERING TALENTS BASED ON 3E

Against the background of Industry 4.0, engineering talent training is facing some serious challenges. To meet the new needs of industry and business for engineering talents, 3E proposed a new personal training program centered on “personal efficacy, knowledge ability, academic ability,

A. New Characteristics of Training Engineering Talent

Facing the changes of new technology, new industry and new society form, the talents of New Engineering have the following 6 features.

To respond to the changes of new technology, new industry and new pattern, engineering talent training is required 6 new characteristics, which are shown as follow:

1) *New Concept*: 3E is regarded as an important reform in higher engineering education and it is necessary to introduce some new concepts. It needs to face the strategic emerging and leading industries to cultivate talents and to reform engineering education according to law and characteristics of 3E.

2) *New Feature*: The main professional features of 3E are informatization, networking, intelligence, crossing, integration and innovation. The primary teaching features of 3E are diversification, practicality and internationalization.

3) *New Knowledge*: 3E is a kind of future-oriented discipline and it necessarily contains some new knowledge, including the new engineering techniques related to strategic emerging industries and the new contents associated with interdisciplinary. Furthermore, 3E will build a new knowledge system and curriculum system.

4) *New Model*: 3E will apply various new teaching models, e.g., the combination of classroom teaching and project practice, inquiry-based learning and small-class learning, MOOC/SPOC teaching and flip class teaching, School-

enterprise cooperation and enterprise internship, international exchange and united training, etc..

5) *New Opportunity*: 3E should provide more opportunities for students, including choosing majors, selecting courses, learning from great teachers, participating in social practice, entering the famous university for further study, etc..

6) *New Talents*: 3E will aim to cultivate many kinds of engineering talents for the development of new industries and new techniques, e.g., innovative talents, researching talents, emerging industrial talents, cross-combination talents, international talents and sustainable development talents.

B. New Goals of Training Engineering Talent

3E aims to develop talents with creative ability, sustainable competitiveness and innovative spirit. More specifically, they need to strengthen their own abilities from two aspects, professional ability and general ability. Professional ability indicates the ability to do theoretical analysis and abstract thinking, the ability to understand and solve problems, the ability to design and implement and system, the ability to test and maintain the system and the ability to study and enhance self-development continuously. General ability refers to the ability to transform knowledge and communicate across different disciplines, the ability to manage project and work as a team and the ability to improve innovation consciousness and strengthen international competitiveness. Furthermore, 3E will cultivate innovative talents with high qualities in the aspects of physical and mental, culture, personality, society, science research, engineering, elitism, professionalism, etc..

Therefore, 3E will construct a multidimensional knowledge system and talent training structure to reserve high-quality engineering talents resources for the country's scientific and technological progress and economic development. The core abilities proposed by 3E is shown in Figure 1.

IV. DIVERSITY TEACHING METHOD BASED ON 3E

A. Diversity of Teaching Concept

3E aims to develop high-level mass education not elite education. It transforms from the teaching-centered to student-centered. Instead of breadth, elite education pays more attention to the depth of knowledge, which will not meet the needs for engineering talents in new economic era. Mass education takes classified cultivation, which divides the traditional disciplines into some new subjects. It enhances the ability of critical thinking, self-learning, design thinking, etc. Mass education can solve the contradiction between the limited time of learning and the infinite growth of knowledge, the variability of real problems and the certainty of knowledge. Therefore, the diversity of teaching must be strengthened to focus on the needs of society and the development of students. The main methods are multidisciplinary integration and flexible training programs.

1) *Multidisciplinary Integration*: To cultivate cross-disciplined talents with the ability of knowledge transfer, it needs to establish a “Giant Discipline” through integrating different disciplines. “Giant Discipline” can achieve

comprehensive educational goals without the limitation of a single discipline. It not only can make students entirely and objectively understand the role of their own discipline in the mapping knowledge domains but also can make them solve the complex problem from various perspectives.

2) *Flexible Training Program*: With the development of "Giant Discipline", it is necessary to cultivate different types of talents according to their characteristics. The students can choose the proper programs based on their professional interests and career planning. Customized training program can make the personalized education a reality.

B. Diversity of Curriculum System

3E needs to establish a new curriculum system according to the engineering logic to develop innovative spirit, enterprising consciousness and creation ability. It is necessary to improve the quality controlling system of engineering talents to take classified cultivation. 3E is actively exploring to establish a new paradigm for developing engineering by means of transforming from discipline-oriented to demand-oriented, from major division to multi-disciplinary integration and from meeting application requirements to leading to the development of industry.

1) *3-Level Teaching System*: The 3-level teaching system indicates basic level, application level and innovation level. Basic level represents the general education, which teaches students the necessary knowledge and basic skills; Application level represents the professional education, which teaches the students domain knowledge and application skills; Innovation level represents the engineering education, which trains the students' engineering thinking and innovative consciousness

2) *3-Stage Engineering System*: The 3-stage engineering system means "experiment stage, practice stage and training stage". In order to solve the problem of disconnection between engineering education and engineering practice, it is an effective way to extend the engineering thinking to all aspects of classroom teaching and extracurricular activities. Combined with the needs of the real projects, some related experiments were designed. 3E will implement an innovation training of combining with work and study and cooperating between university and industry.

C. Diversity of Evaluation Mechanism

In particular, we should establish a perfect evaluation mechanism which can be improved continuously. It includes three sub-mechanisms, they are quality monitoring, graduates tracking and social evaluation. To ensure its effective implementation, 3E mainly focuses on the improvement of three aspects of training objective, graduation requirements and curriculum system and it will continually enhance the rationality and consistency of these three aspects. To this end, we need to pay attention to the following three points.

1) *Evaluation*: Evaluation is used as the basis to realize the sustained development of training. It is asked to provide

correct data and give reasonable results, which needs to make clear the object, standard and executor of evaluation and apply the effective evaluation method in the proper evaluation cycle. Evaluation should truly reflect the performance of evaluated objects base on the effective collection and in-depth analysis of the original data.

2) *Mechanism*: Mechanism is regarded as guarantee, which is used to ensure the sustainability and effectiveness of evaluation. Only when the mechanism is perfect and efficient, the evaluation can be improved continually. It should establish a set of standard evaluation processes for quality monitoring, graduates tracking and social evaluation. Furthermore, it should well-defined the personnel involved in these processes and their respective responsibilities.

3) *Improvement*: Improvement is the goal. 3E will improve the evaluation with feedback of actual results into itself. Making improvement based on the evaluation result is feasible, effective and well-founded.

D. Diversity of Teaching Model

1) *To Establish an Experimental Class*: 3E will establish an experimental class to cultivate outstanding creative talents and a new syllabus with strong engineering features will be designed across two dimensions, the school training standard and the industry training standard. It can make the enterprises deeply involved in the training of the students and make the university to implement refined management of teaching.

We should establish a perfect education system which supports the development of "creation-innovation-entrepreneurship". It aims to cultivate engineering talents with high qualities of innovation, diversity, sustainable development and inter-disciplinary. Specifically, 3E actively explores to establish a new type of innovative training mode and perfects the entrepreneurship curriculum and related management system. It strengthens the innovation and entrepreneurship education, which is a part of general education, to improve the students' social adaptability and competitiveness and designs a set of frontier courses, comprehensive courses, problem-oriented courses and interdisciplinary courses. It actively tries to offer diversity training, e.g., interdisciplinary or dual-degree programs, "engineering +", double major, and pays more attention to entrepreneurial orientation in the process of graduation design. It promotes the construction of innovation and entrepreneurship platform with the feature of engineering and encourages students to participate in innovative activities and entrepreneurial practice. The expected results of this work should include: obtaining an effective method for cultivating innovative engineering talents, establishing an entrepreneurial oriented training mode and forming a marketed employment mechanism to promote the close combination of industry, education, research and application.

2) *To Implement Engineering Tutorial System*: 3E will adopt an engineering tutorial system who regards the project as carrier, the student as center and the tutor as orientation. According to the personality characteristics of students, personalized tutoring can be achieved.

For realizing the student-centered teaching objective and meeting students' individual needs, 3E explores a new engineering education pattern with the features of “project-driven, student-centered and teacher-directed”. 3E develops the engineering training system from the following aspects. It develops individual and innovative engineering education through summarizing and studying some internal and international related experience and researching and analyzing the students’ thinking mode, learning objective and interests in the internet economical era. It encourages students to achieve their career development and life planning under the guidance of their tutors by providing rich and diverse teaching resources and allows students to choose and replace a major more freedom. It implements “top-notch talent” plan to fully display students’ natural talent and specialty. It offers resources guarantee and supporting condition for independently designing training program and discipline evaluation criterion. It improves the quality-evaluation training system according to everyone's characteristics and perfects the curriculum system and training program continually. The expected results of this work should include: forming a student-centered personnel training program, formulating some effective and helpful management models and operating mechanisms and providing the valuable experience based on case and data.

V. CONCLUSION

By all concerns above to enhance 3E there are altogether 7 works should be carried out to achieve successfully construction of a high-quality eco-system for both universities and industry: (1) renewing the educational concept, namely, to clear the educational concept with industry demand and sustainable competitiveness; (2) building the first-class teacher team of multidisciplinary integration with the cooperation of universities and industry; (3) innovating the professional knowledge system and curriculum system with leading industry; (4) innovating the training model of talent in accordance with the law of new engineering development; (5) creating multi-dimension learning and practice platforms for students, that is, the environment of interdisciplinary learning and discussion; (6) building a good innovation and entrepreneurship education; (7) introducing the international cooperation partners, making the international training

programs the basic ways to cultivate the international competitive talents. After all, the key methods are multidisciplinary integration and flexible training programs to make all these works.

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	Personal effectiveness	Knowledge ability	Academic ability	Technical ability	Social competence
Must have	<ul style="list-style-type: none"> Lifelong learning Integrity Initiative Professionalism 	<ul style="list-style-type: none"> Mathematics Science Social and Humanity Art Fundamental of Engineering 	<ul style="list-style-type: none"> Problem solving Critical thinking System thinking Effective communication 	<ul style="list-style-type: none"> Data and information processing Network security & data protection Programming Human-computer interaction 	<ul style="list-style-type: none"> Engineering ethics Effective communication Team collaboration
Should have	<ul style="list-style-type: none"> Adaptability Share perspective Understand others Self-esteem 	<ul style="list-style-type: none"> IT Health and security Artificial and Intelligence Manufacturing Process 	<ul style="list-style-type: none"> Quantitative reasoning Information literacy Innovation and Entrepreneurship Decision-making 	<ul style="list-style-type: none"> interdisciplinary ability ICT knowledge and ability Trust new technology Design thinking 	<ul style="list-style-type: none"> Global thinking Interpersonal interaction Leadership
Can have	<ul style="list-style-type: none"> Self management Time management Patience Transformative Capability 	<ul style="list-style-type: none"> Commerce and finance computer networkIng environmental Science The science of law 	<ul style="list-style-type: none"> Academic writing Knowledge management Self evaluation 	<ul style="list-style-type: none"> Statistical knowledge Understanding knowledge and process Comprehensive application 	<ul style="list-style-type: none"> Contemporary problems Acceptance of uncertainty Spirit of adventure

Figure1 Education at a glance:graduates and entrants by field. OECD(2016)