The Mechanism of the Engineer's Cultivation through Combining Training with Scientific Research——Practices and Cases of Training Excellent Engineer in National University of Defense Technology (NUDT)

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Proficiency in professional engineering skills is critical for success in the multidisciplinary, intercultural team interactions that characterize 21st century engineering careers. [1]With the further development of engineering education and knowledge economy, the cultivation of scientific and engineering talents with outstanding research capability has been increasingly urgent. However, the development of scientific research capability has been a relatively weak link in the engineering education of China for a long time, and is also a missing link in the engineering education all over the world today. A U.S. National Science Foundation's report, In Restructuring Engineering Education: A Focus on Change, recommended that engineering courses include early and continued exposure to environmental, political and social issues and their international and historical contexts, as well as legal and ethical implications of engineering solutions. [2]To ensure continued quality of leader-level engineers in the rapidly changing environment of the world economy and needs, engineering education must help engineer integrate professional and technical skills for more robust problem solving. [3,4,5,6,7]The key to foster a large number of engineering technology talents with strong research capability depends on whether the development mechanism is scientific and reasonable. Currently, the traditional talent development mechanism still dominates engineering education, which is unfavorable to the cultivation and mass emergence of outstanding engineering talents in the knowledge economy era. [8]

Engineering education and research are also mainly based on the elements of education, and there is a shortage of researches on the career development of engineers, especially on the construction of a mechanism combining engineering practice and application, scientific research capability and engineering education. Thus, to solve the problem of scientific research capability inadequacy of engineers and consequently to build a bridge between engineering education and scientific research, it is definitely demanding ? to establish a high-level development mechanism. In order to enhance the scientific research capability of engineers, especially excellent engineers, National University of Defense Technology (NUDT) organized three seminars for excellent engineers, discussing and exploring relevant theories and practices on the integrated mechanism of engineering education and scientific research.

I. Literature Review

At present, countries around the world are used to represent the concept of scientific research with "research and development" ("R&D"). Scientific research can be divided into four levels: to elaborate researches of predecessors, to validate researches of predecessors, to improve researches of predecessors, and to create original researches. No matter at which level, a research should include creative work of the researcher.[9] According to Oxford English Dictionary and the Organization for Economic Cooperation and Development (OECD), "The purpose of research and development is to grow knowledge. Knowledge includes the exploration of human culture and social knowledge as well as systematic creative work for the invention of new usages with such knowledge." [10] The research and development capacity of an engineer refers to the capability of an individual or a team, with relevant background and knowledge in science or engineering, to engage in scientific research activities in such areas as the development, production and service of engineering or technology. [8,17] It mainly includes theoretical thinking ability, creative ability, practical ability and the ability to organize scientific and research activities. A large number of studies, both at home and abroad, show that scientific research capability can be cultivated through engineering education. Yuan Yi and Lao Chunyan proposed creating a cultivation mode of new-type engineering and technology talents, executing interactive teaching, teaching combined with scientific research, and the measures to develop the scientific research capability of new-type engineering and scientific talents. [11]

Based on the cooperative education in cultivation mode of outstanding engineering talents, the measure Zeng Li Jun, Liu Hui, etc. proposed taking full advantages of scientific research institutes, colleges and enterprises, to enhance the practical engineering capability through theoretical teaching combined with engineering practice production capability and scientific research capability. [12] In response to the "Plan on the Education and Development of Excellent Engineers" brought up by the Ministry of Education and the requirements to develop innovative application talents, Liu Da Yu etc. emphasize lifting the scientific research capability and industrial technology supporting capability of innovative talents through higher education level, practice in scientific research projects, working experience, practice in production combined with learning and research and other methods. [13]

Taking the Economics and Management College of Tianjin University of Technology and Education (TUTE) for instance, Meng Fan Hua and Zhong Cong You analyzed existing major problems in the development of scientific research capability of youth teachers in colleges, studied the causes for the problems, and discussed how to raise scientific research capability of youth teachers. [14] According to Fang Peng and Gao Yao, a study on the development of innovative engineering scientific talents on working stage can be conducted through establishing macro policies and a social environment that are suitable for the cultivation and development of innovative talents as well as implementing micro organizational measures favorable to the enhancement of innovative capability of individuals. [15] According to the foregoing studies, the scientific research capability of engineers may be cultivated through engineering education.

The development mechanism for the scientific research capability of engineers refers to a linking and operation method where each component of the development system coordinates and promotes each other. According to relevant studies both at home and abroad, the development mechanism for scientific research capability of engineers can be generally classified into four dimensions, including policy guarantee mechanism at the national level, engineering education mechanism at the college level, synergic development mechanism at the industry level, and drive mechanism at the individual level. The specific measurement indexes and the bibliography are set forth in Table 1[17]. Due to word count limitation, this paper only lists part of the measurement indexes.

Table 1 Dimensional and Measurement Indexes of the Development Mechanism of Scientific Research of Engineers (Partial)

Dimension	Measurement Indexes
Policy guarantee mechanism at the national level	Implementation effect of the development plans for engineering science talents at the national level
	Support from relevant laws and regulations
	………………
Engineering education mechanism at the college level	Communication effect of the leading or cutting-edge technology knowledge
	Open and interactive teaching mode
	Communication and cooperation with colleges both at home and aboard
	Effect evaluation and feedback mechanism
	…………
Synergic development mechanism at the industry level	Establishment of college-enterprise cooperative organizations
	Guidance by business coaches in college
	Sites provided by enterprises for practice, etc.

	……………
Drive mechanism at the individuals level	Personal quality of scientific talents
	Scientific research capability of scientific talents
	Cooperative research and team organization
	…………..

II. Research Hypothesis

See Table 2 for the hypothesis on the relations between each dimension of the development mechanism for the scientific research capability of engineers and each component of scientific research capability.

Table 2 Hypothesis of Relevance between the Development Mechanism for the Scientific Research Capability and Components Comprising the Scientific Research Capability of Engineers

Hypothesis	Details	Hypothesis	Details
A1a	The policy guarantee mechanism at the national level is positively related to the theoretical thinking ability of engineers.	C1a	The synergic mechanism at the enterprise level is positively related to the theoretical thinking ability of engineers.
A1b	The policy guarantee mechanism at the national level is positively related to the creative ability of engineers.	C1b	The synergic mechanism at the enterprise level is positively related to the creative ability of engineers.
A1c	The policy guarantee mechanism at the national level is positively related to the practice ability of engineers.	C1c	The synergic mechanism at the enterprise level is positively related to the practice ability of engineers.
A1d	The policy guarantee mechanism at the national level is positively related to the ability of engineers to organize scientific research activities.	C1d	The synergic mechanism at the enterprise level is positively related to the ability of engineers to organize scientific research activities.
B1a	The scientific research education mechanism at the college level is positively related to the theoretical thinking ability of engineers.	D1a	The drive mechanism at the individual level is positively related to the theoretical thinking ability of engineers.
B1b	The scientific research education mechanism at the college level is positively related to the creative ability of engineers.	D1b	The drive mechanism at the individual level is positively related to the creative ability of engineers.
B1c	The scientific research education mechanism at the college level is positively related to the practice ability of engineers.	D1c	The drive mechanism at the individual level is positively related to the practice ability of engineers.
B1d	The scientific research education mechanism at the college level is positively related to the ability of engineers to organize scientific research activities.	D1d	The drive mechanism at the individual level is positively related to the ability of engineers to organize scientific research activities.

III. Research Design

1. Questionnaire design

The design of the questionnaire mainly includes the essential indexes for the scientific research capability of engineers and specific measurement indexes of each dimension of the development mechanism. The measurement indexes involved in each dimension of the development mechanism come from relevant research literature (refer to Table 1 for details) and are determined after a small range of forecast and filtering.

2. Samples and data collection

The objects of the questionnaire are 124 participants participated in three engineer talent seminars organized by NUDT, where the participants are surveyed pertinently in terms of their education experience, working experience as engineers, capability development, large project cultivation mode and other aspects by means of questionnaire and interview. Then reliability analysis and validity verification of the result were carried on.

3. Preliminary design of the cultivation program

While preparing the cultivation program of outstanding engineer seminars, the following points has been considered prudently: (1)a high perspective. Formulate teaching plans at strategic level and from global vision to transfer the participants from common engineers to strategic scientists. (2)selected curriculum. Insist on high-end teaching. Invite academicians in relevant fields or top scientists as lecturers for all courses. (3)wide range covered. The content of teaching should cover all the main areas of today's development on cutting-edge science around the world, and the teaching should be organized in a systematic manner.(4)new knowledge passed. The newest knowledge should be taught based on leading science development both at home and abroad.(5)practical results. The practical demand of the participants for work should be met and good results obtained in a short time. The goal of cultivating engineers is to help them: be aware of the scientific competition situation over the world and master leading knowledge in science and technology development through following up; understand the scientific and technological innovation required by the national economic construction and informatization development; conduct further studies on material issues in the latest development of information technology, especially issues closely related to their own job; further understand their own important roles and special responsibilities in national information technology construction and major engineering construction practice, and make every effort to become high-quality innovative talents with abilities and integrity.

IV. Analysis of Scientific Research Capability Data

Components comprising the scientific research capability mainly include theoretic thinking ability, creative ability, practice ability, and the ability to organize scientific research activities.[16]

1. Participants' structure

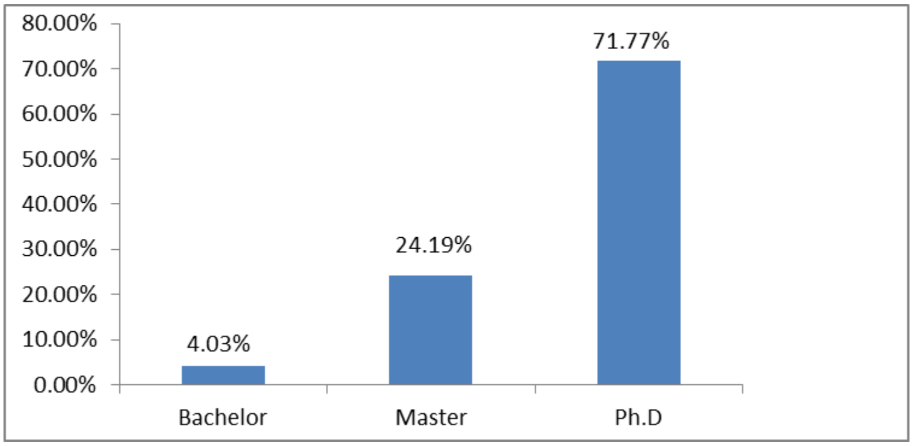
There are 124 participants attended the three outstanding engineer seminars. Their basic information is as follows: 51 middle-age and young participants below 45 years old (inclusive), accounting for 41.13%.

Table 3 Age Distribution of Participants in the Three Outstanding Engineer Seminars

Age range	<40	41~ 45	46~ 50	>51
Number of participants	16	35	56	17
Percentage	12.90%	28.23%	45.16%	13.71%

In terms of the education background and education experience of the participants, most of them are highly educated or studied abroad. The majority have doctor's degree, accounting for about 71.77%. There are still a large number of participants holding master's degree or bachelor's degree, accounting for 24.19% and 4.03% respectively.

Chart 1 education background of the participants

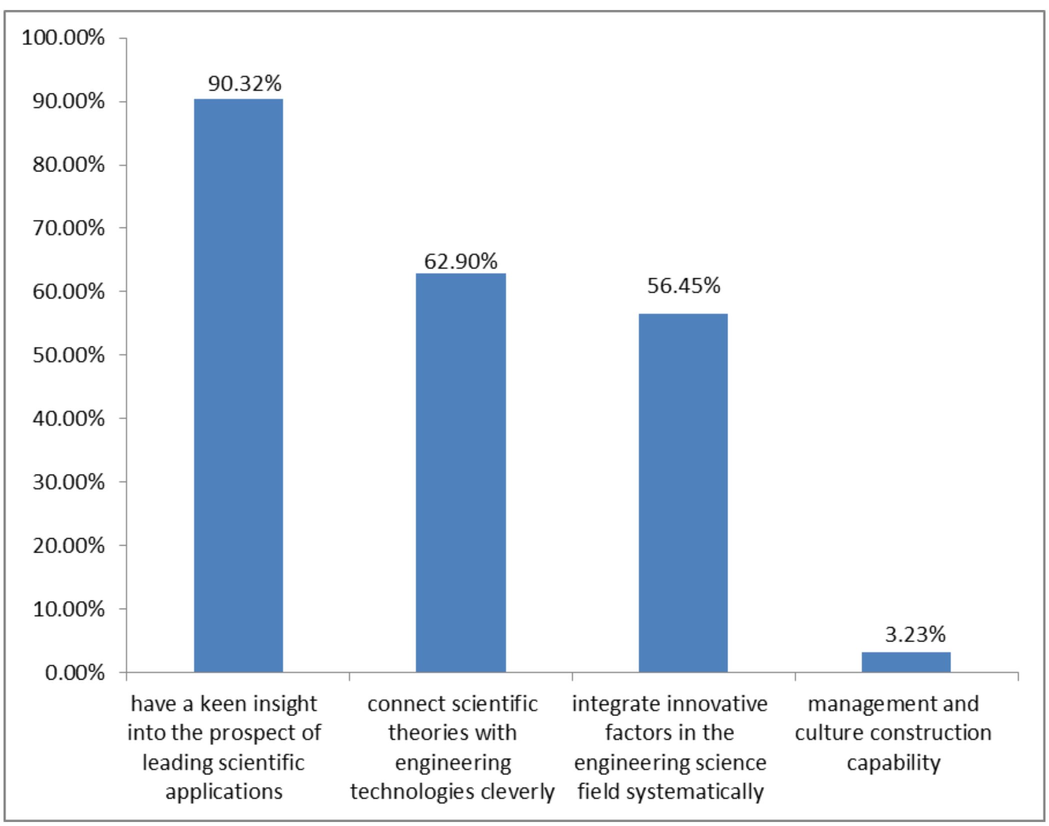


Among which, 22 participants served as visiting scholars, accounting for about 20.75%; 66 attended international conferences, accounting for about 62.26%; 50 investigated abroad, accounting for about 47.17%.

2. Theoretical thinking ability

In terms of special quality that should be strengthened by outstanding engineers, 90.32% of the respondents think they should have a keen insight into the prospect of leading scientific applications; 62.90% claim they should be able to connect scientific theories with engineering technologies cleverly; 56.45% argue they should be able to integrate innovative factors in the engineering science field systematically; besides, 3.23% suppose outstanding engineers shall have the management and culture construction capability.

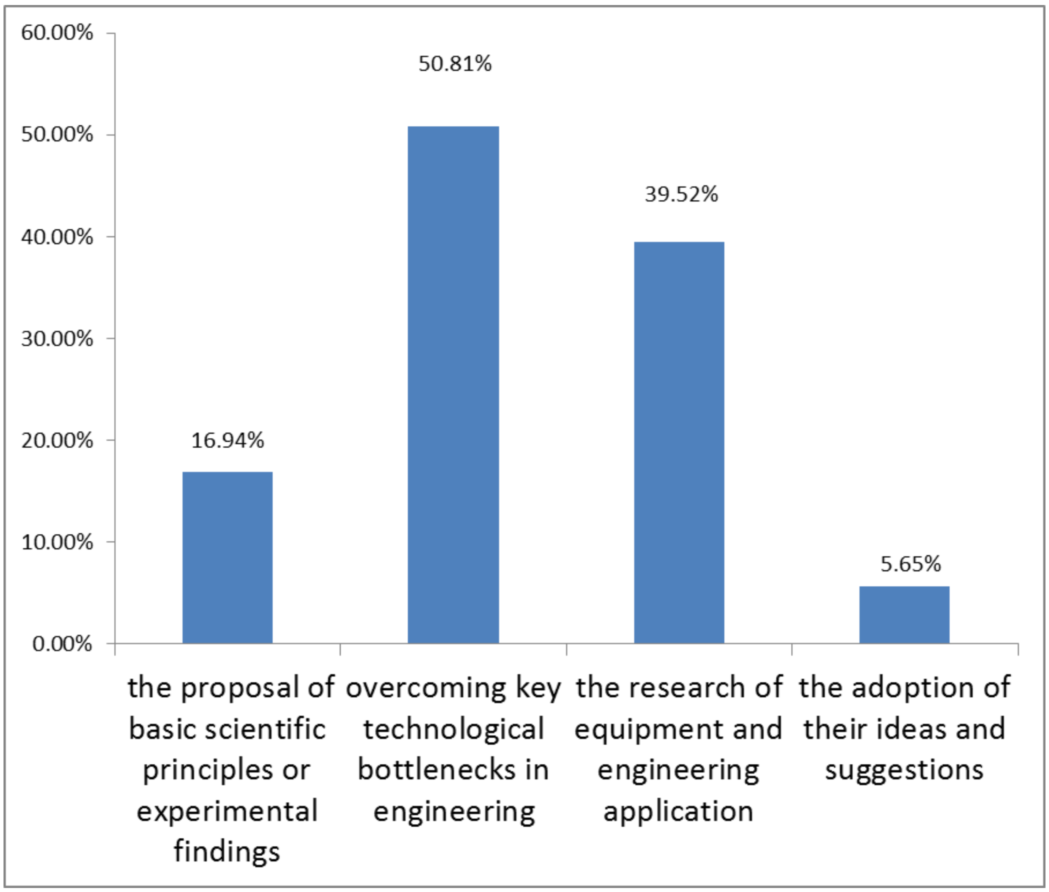
Chart 2 special quality that should be strengthened



3. Creative ability

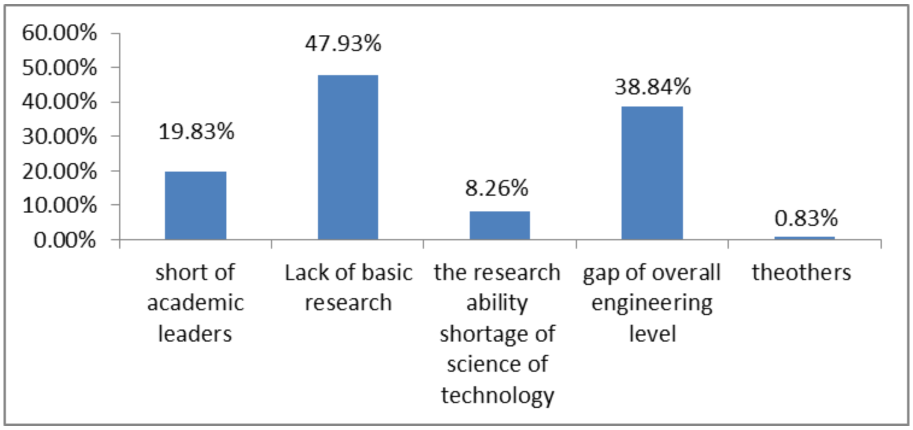
(1) The creative ability is mainly reflected in the sense of achievement in scientific research. To realize engineering application and obtain benefits is the major source of sense of achievement for scientific researchers. Among which, 50.81% of the respondents obtain the sense of achievement mainly from overcoming key technological bottlenecks in engineering; 39.52% of them gain the sense of achievement mainly from the research of equipment and engineering application; 16.94% acquire the sense of achievement mainly from the proposal of basic scientific principles or experimental findings; besides, some others obtain the sense of achievement from the adoption of their ideas and suggestions.

Chart 3 major source of achievement for scientific researchers



(2) The major gap between engineers in China and those in developed countries is mainly reflected in:

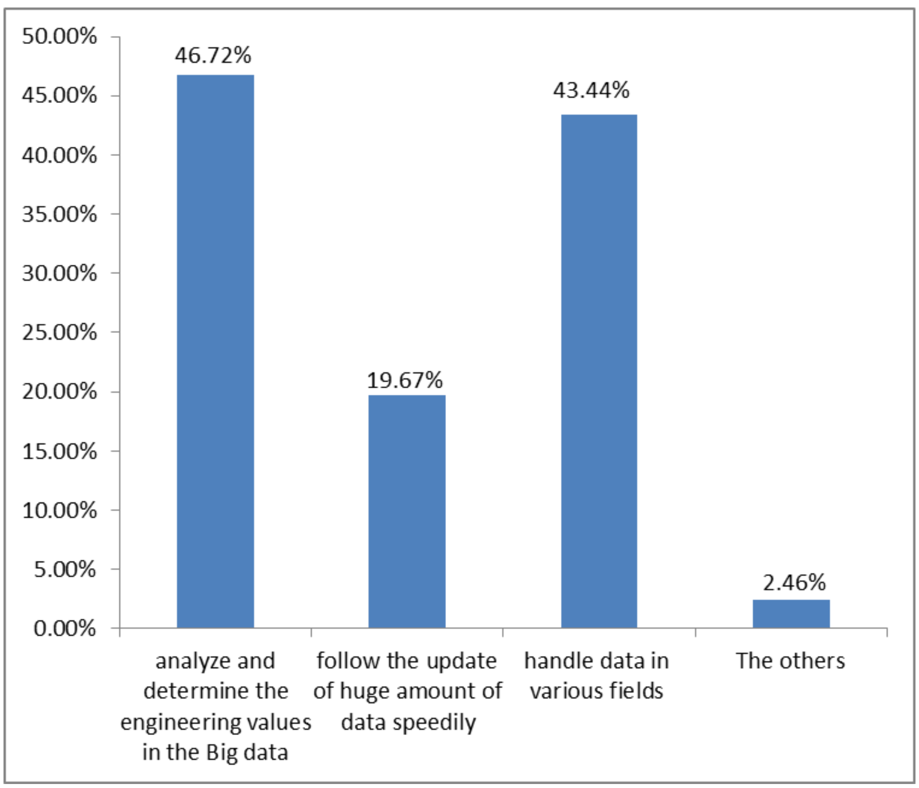
Chart 4 major gap between engineers in China and developed countries



4. Practice ability

(1) With respect to the challenges raised by the big data era to the competency of engineers, 46.72% of the respondents think engineers should be able to analyze and determine the engineering values in the Big data, 43.44% argue engineers should be able to handle data in various fields under disciplines highly differentiated on the whole, and 19.67% claim engineers should be able to follow the update of huge amount of data speedily.

Chart 5 major challenges raised by the big data era to the competency of engineers

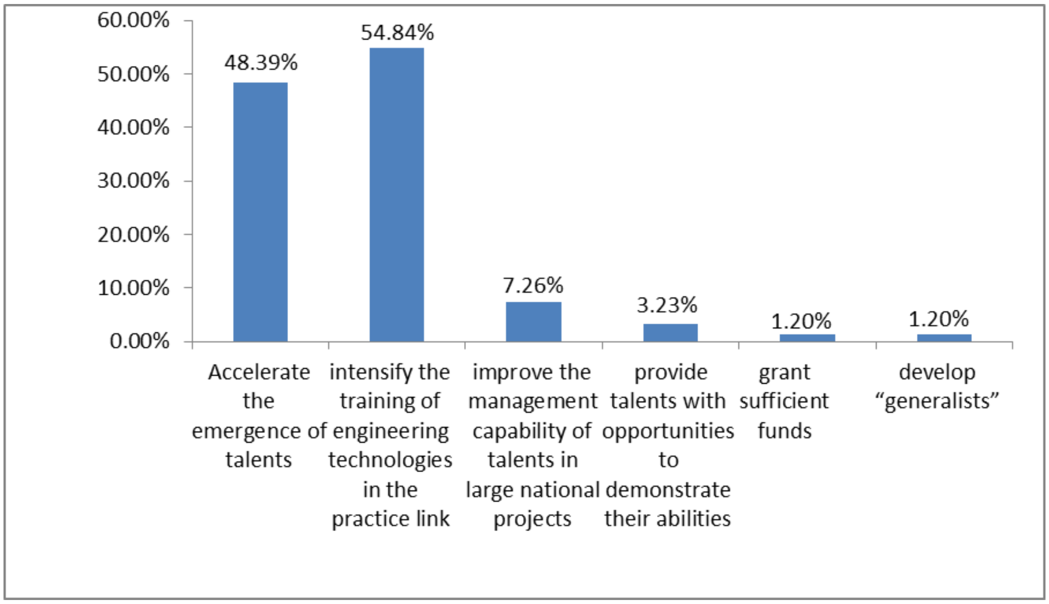


Is the big project mode favorable to the cultivation of talents? In the questionnaire, the author conducts a survey as to the advantages and disadvantages of the big project mode for talent cultivation.

(2) Regarding to the advantages of talents cultivation in big projects, 54.84% of the respondents think big projects intensify the training of engineering technologies in the practice link; 48.39% regard big projects as accelerating the emergence of talents; 7.26% claim big projects improve the management capability of talents in large national projects; and some others argue big projects

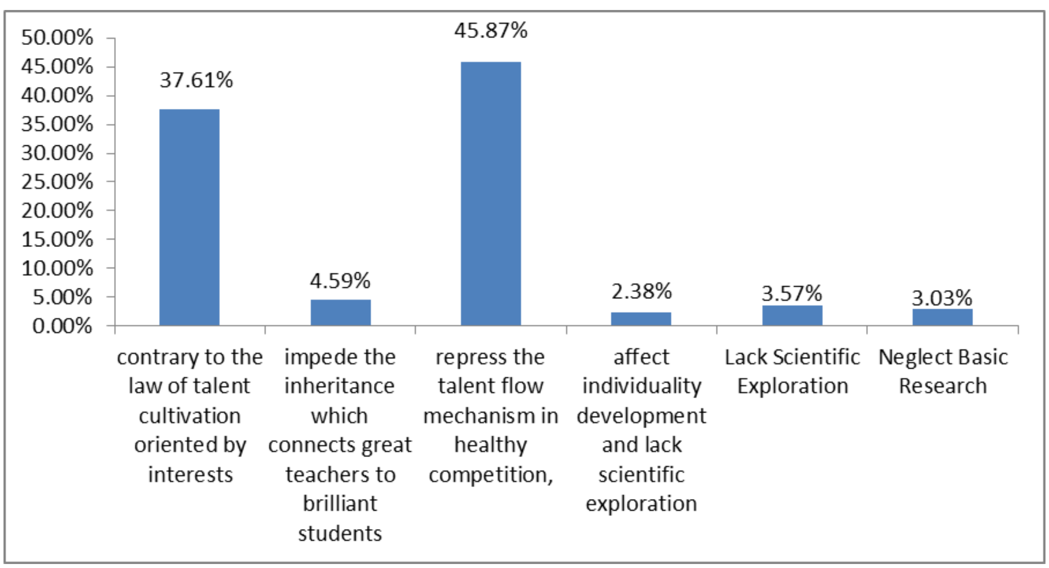
provide talents with opportunities to demonstrate their abilities (2.38%), grant sufficient funds (1.20%) and develop "generalists" (1.20%).

Chart 6 advantages of talents cultivation in big projects



Regarding to the disadvantages of talent cultivation in big projects, 45.87% of the respondents think big projects repress the talent flow mechanism in healthy competition, 37.61% of them think big projects are contrary to the law of talent cultivation oriented by interests, 4.59% think big projects impede the inheritance which connects great teachers to brilliant students, and 2.38% think big projects affect individuality development and lack scientific exploration. 3.57% think lack scientific exploration and 3.03% neglect basic research.

Chart 7 the disadvantages of talent cultivation in big projects



5. Ability to organize scientific research activities

(1) The main mode of the participants' engagement in scientific research work: Mainly the collaboration between small-scale academic communities and the tackling of key problems with

large-scale scientific research teams, accounting for 48.78% and 43.90% respectively.

Chart 8 The main mode of the participants' engagement in scientific research work

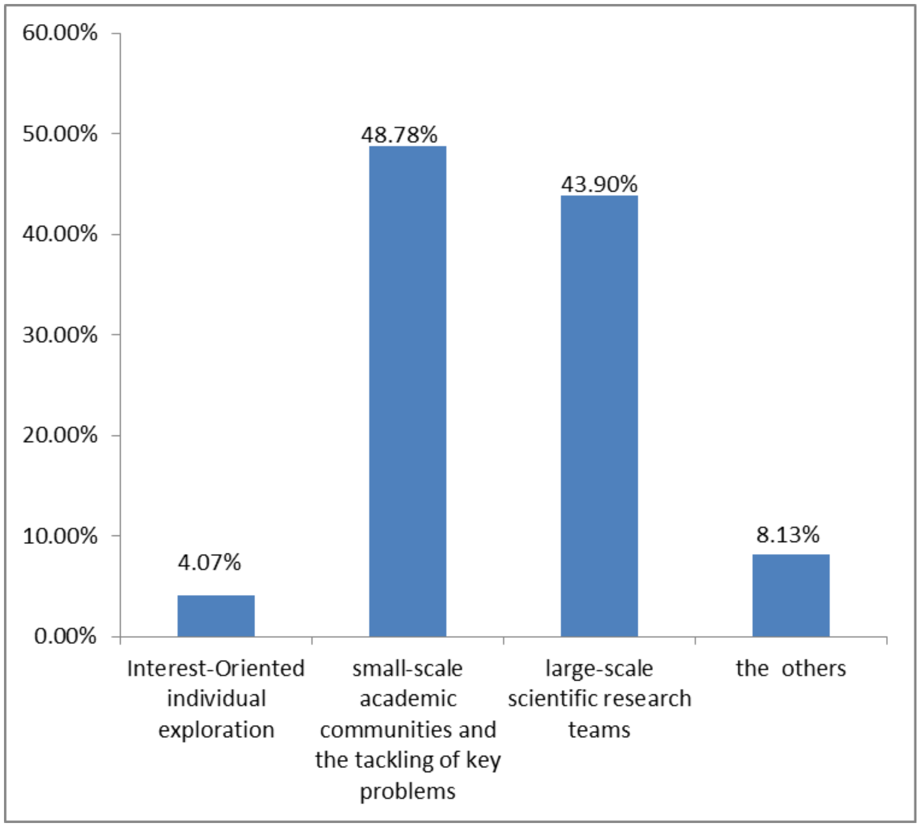
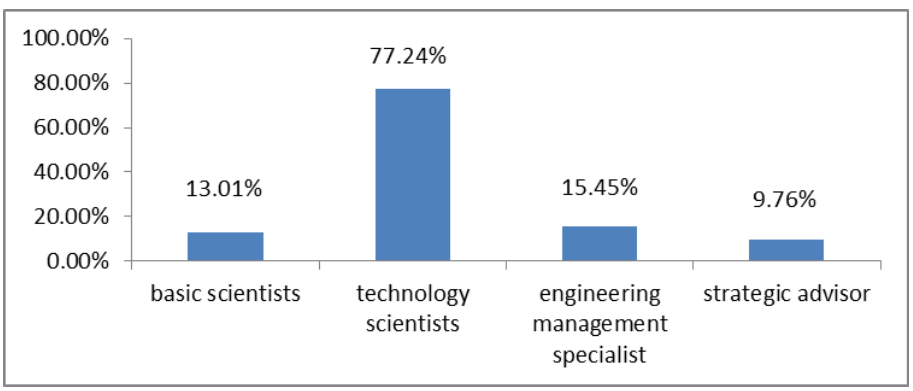
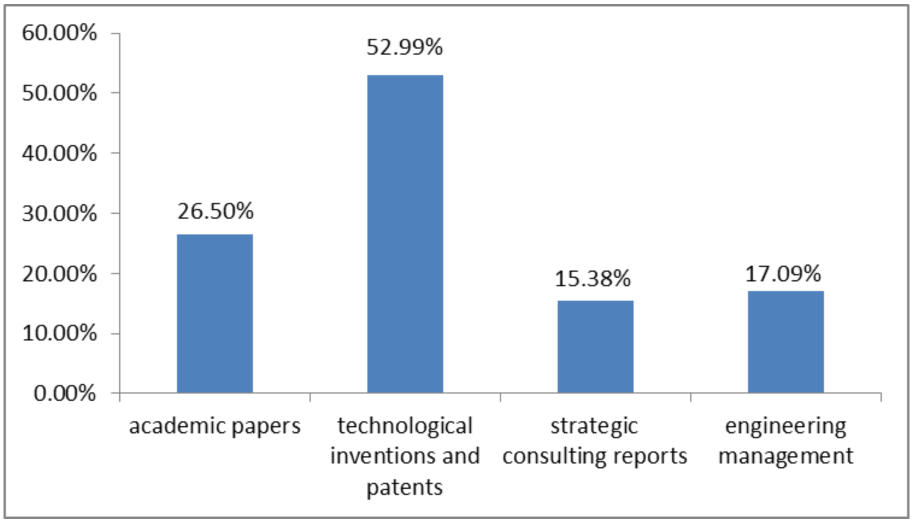


Chart 9 Main roles they play in scientific research: (multiple choice)



(2) As for the type of research result contributes significantly in scientific research, 52.99% of the engineers think technological inventions and patents play a key role for them to stand out in the scientific research field, 26.50% think academic papers, 15.38% think strategic consulting reports, and 17.09% think engineering management would have such effect.

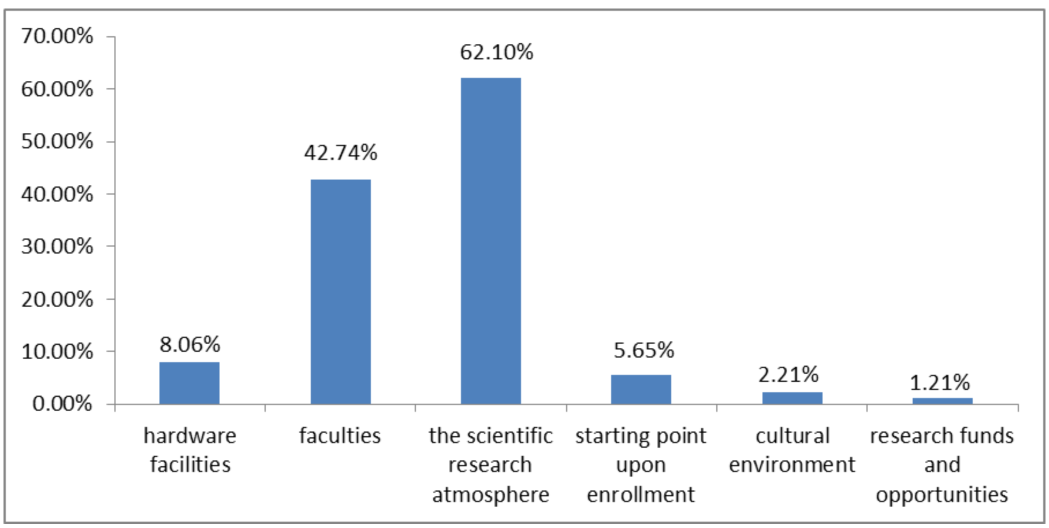
Chart 10 the type of research result contributes significantly in scientific research



6. Survey on engineering education conditions

(1) Regarding to the choice of engineering education, according to statistics in Figure 1, 62.10% of the engineers consider the scientific research atmosphere in college as an important factor that affects their development, and 42.74% consider faculties do. By contrast, fewer engineers choose factors such as hardware facilities, starting point upon enrollment, research funds and opportunities, cultural environment, accounting for 8.06%, 5.65%, 1.21%, 2.21% respectively.

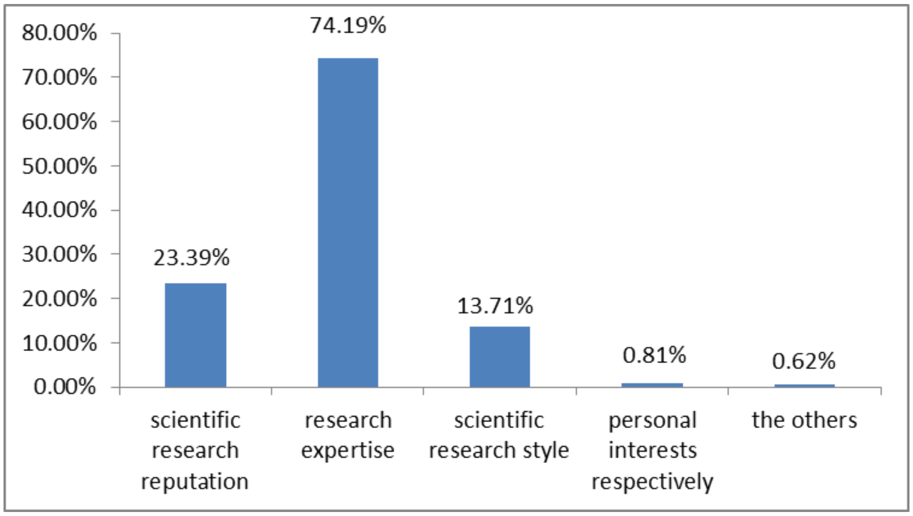
Chart 11 the Factor affect the choice of engineering education



(2) Regarding to supervisors, the questionnaire focuses on three aspects:

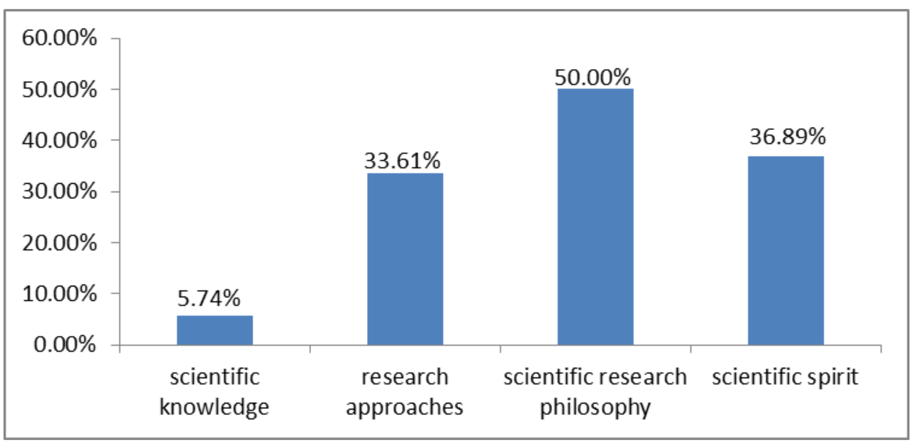
The basis for supervisor selection: 74.19% of the participants choose research expertise as the basis for their selection of supervisors, and 23.39%, 13.71% and 0.81% select the scientific research reputation, scientific research style and personal interests respectively. Thus, while choosing supervisors, engineers not only consider the supervisors' reputation in scientific society, but also consider their own interests and advantages as well as the research fields the supervisors are good at.

Chart 12 The basis for supervisor selection



(3) As for the most significant impact of a supervisor on the development of the scientific research quality of an engineer, 50.00% of the participants choose scientific research philosophy, 36.89% and 33.61% choose scientific spirit and research approaches respectively, and 5.74% choose scientific knowledge. Seen from this point, the passing on scientific knowledge is not a main component of high-level engineering education any more. For over half of the engineers, the focus of their learning with the supervisors is research philosophy, so that they can choose innovative paths on their own according to their interests and advantages, and not necessary to follow the existing research approaches and research modes of their supervisors.

Chart 13 significant impact of a supervisor on the development of the scientific research quality



V. Engineering Education Practice

In order to establish an engineering education development mechanism based on the foregoing analysis of scientific research capability, we have established a new curriculum design system from four aspects, such as policy guarantee mechanism at the national level, engineering education mechanism at the college level, synergic development mechanism at the industry level, and drive mechanism at the individual level.

Table 4 Curriculum System for the Scientific Research Capability Improvement of Outstanding Engineers

Subject	Course
Subject One: policy guarantee mechanism at the national level	
Course 1: Science and Technology Development Strategies and Information Technology Construction	Focus on the learning about the development trend and application of the leading science and technology of the world, the development history, policies and strategic planning of China's science and technology, master the direction and focus

	of the future development of national defense technology, and understand the focus of innovation and research of engineers in their professional fields.
Course 2: Strategies and Policies of Scientific and technological Innovation of China	Understand China's medium and long-term science and technology development plans, the "Twelfth Five-Year" science and technology planning, innovation-driven development strategies, national science and technology innovation system construction and its policies and measures, etc.
Course 3: Study on the National Information Technology Development of China	Study the basic characteristics of the information technology construction in major countries of the world and China, the current situation of the information technology construction, the development ideals and goals, and the focus and direction of the development of information technology of China in the future.
Subject Two: Course Engineering Education mechanism at the College Level	
Course 1: Scientific and Technological Innovation Epistemology and Methodology	Focus on learning about the latest development of engineering innovation and technological innovation theories, philosophical thinking methods and application, scientific methodology, etc., discuss and apply philosophical thinking and scientific methodology, master the essence of scientific problems, and adopt ideas and measures for innovation research.
Course 2: Technological Innovation Theory: Methods and Application	Learn and communicate about basic theories, methods and the latest development of technological innovation, and discuss the way to apply technological innovation theories and methods in the field of science and technology.
Course 3: Philosophical Thinking and Scientific and Technological Innovation	Learn and communicate about theories and methods for philosophical thinking and their application, discuss about the way to apply philosophical thinking theories and methods in engineering research innovation practice.
Subject Three: Synergetic Mechanism at the Industry Level	
Course 1: Development Trend and Impact Science and Technology of the World	Understand the development trend of science and technology of the world and its major characteristics, understand the latest development of major leading-edge technologies in engineering, and grasp the focus and direction of the development of science and technology of China.
Course 2: Engineering Innovation Practice and Thinking	Focus on the learning and communication about basic scientific research, tackling problems in key technologies in major national projects and major science and technology projects.
Course 3: 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 innovative practice of grasping innovation direction in engineering practice and making breakthrough in core technologies.
Subject Four: Drive Mechanism at the Individual Level	
Course 1: Logic of Scientific Findings	Learn the basic theory on scientific discovery, understand the latest research results of relevant theories both at home and abroad and the application, and discuss about the way to apply scientific methodology in engineering innovative practice.
Course 2: Basic Scientific Research Innovation and Experience	Learn and communicate about grasping the direction of innovation, constructing innovation teams, tackling key problems in scientific research and acting as an internationally frontier leader in innovation practice experience in biology, information and other fields, and reflect on the direction and focus of the basic scientific and technological innovation research in the area of expertise.
Course 3: Major Engineering Practice and Thinking	Learn and communicate about the cross-disciplinary organization and management system in the major scientific and technological project "Tianhe", Tianhe's team and culture and the experience in the construction of system quality management and other aspects, and reflect on the focus and mechanism measures for the scientific research management and team building of major scientific and technological projects.

i. Measures for Training Organization

1. Measures for enhancing the theoretic thinking ability

The first objective under the training program is to strengthen the epistemological and methodological teaching of scientific and technological innovation. We shall emphasize the research on the guidance function of Marxist philosophy on scientific and technological innovation; improve the cultivation of strategic thinking, dialectical thinking and innovative thinking; further broaden the view of science and technology of the participants; analyze problems with a comprehensive and development point of view; and master the inherent rules of scientific research in contradictory unity. The second objective is to focus on interpreting the scientific thinking of preceding scientists such as Qian Xue Sen. Make the participants further establish an overall thinking framework of "system view, macro strategies, top-layer design, hall systems for workshop of metasynthetic engineering from the qualitative level to the quantitative level, etc.", and gradually form a systematic, comprehensive and creative thinking quality required for a strategic scientist. [18]

2. Measures for enhancing the creative ability

We should attach much importance to the teaching system that integrates the depth of scientific research and the breadth of disciplines, then set relevant subjects and general courses, and further lay a solid foundation for the scientific and technological innovation of the participants. On one hand, teaching about the development trend of science and technology around world should be emphasized. Taking full advantages of national strategic scientists and top experts at the frontier of science and technology, the teaching priority should be placed on internationally leading theories in science and technology, interdisciplinary knowledge as well as the significant impact on military, etc., so that the participants can further establish a global vision and have a keen insight into the international development trend of science and technology. On the other hand, we shall strengthen the teaching about scientific and technological development strategies of China. Analyze deep contradictions restricting the development of China and interpret the further strategic development planning, so as to help the participants understand the position of their work in national scientific and technological development strategies on the whole, further broaden their strategic vision, and lift their thinking levels.

3. Measures for enhancing the practice ability

Firstly, teaching about scientific and technological innovation and modern management practice should be strengthened. On the premise of learning major theories on modern management seriously, the participants' following abilities will be improved by mean of interpreting real cases on modern scientific and technological management, such as to unite various kinds of talents with different personalities and different specialties, learn to create a relaxing, democratic and harmonious innovative atmosphere, excite innovative inspiration in collision of thoughts, form creative ideas in brainstorm, and to obtain innovative results in tackling key problems with the collection of wisdom. Secondly, we should focus on the teaching mainly about information technology construction, then grasp the demand for constructing information technology of China, understand new demands of the latest development of the Internet for scientific and technological innovation, and master the transformation and action mechanism of the economic development based on the information system, etc., so as to clarify the focus and direction of scientific and technological innovation development all over the world and make scientific and technological innovation more energetic and vital.

4. Measures for enhancing the ability to organize scientific research activities

In order to improve cultivation, we arranged a supervisor for each outstanding engineer based on the questionnaire result, making every effort to enhance their ability to organize scientific research activities. First, the research on major scientific and technological problems is emphasized. We will create heuristic, case-based and interactive teaching approaches, and hire academicians from the Chinese Academy of Sciences and Chinese Academy of Engineering as well as prestigious experts to discuss and interact with participants face to face. Also, according to scientific and technological innovation practice, we shall obtain a number of research results with strong ideological content and good practice value in terms of national development strategies for science and technology, independent innovation in engineering machinery, development of scientific and technological leaders, construction of innovative teams and other aspects. Second, cooperative agreements on scientific research shall be reached over common concerns. Given the complementarity among participants in various occupations and from all over the country, they can inspire each other, conduct researches together and reach cooperative agreements on scientific research by means of team discussion, engineer forums, communication at conferences, etc., so as to lay a foundation for subsequent studies on relevant issues.

In subsequent training organizations, we also found some problems existed in the training of engineers for scientific research capability.

(a) In this engineering study area with distinct applicability and task directivity, technological inventions and patents are the main content of scientific and technological innovation of engineers, and breaking through key technologies in the engineering field is still an essential factor for the acceleration of economic mode transformation.

(b) Basic theory research is the engine that drives scientific and technological innovation, but scientific and technological innovation talents in China is relatively weak in this field.

(c) For outstanding science and technology talents, how to give consideration to strategic consultation and engineering management while engaging in specific technology research and development is also a question worth thinking about.

VI. Conclusion

With the continuous development of the world economy and society, new challenges have been brought to international engineering education. Different from liberal arts education, the development of engineering education, as a kind of professional education, is influenced by the game playing between scientific thought and pragmatistic thought. [19] Building an engineering education curriculum mechanism applicable to improve scientific research capability is still a major practical problem in the development of engineering education. Thus, for building an engineering education and training system in a scientific manner, it is prerequisite to keep deepening the study on scientific research capability of engineers, figure out the root of the mechanism for enhancing scientific research capability and further construct the engineering education curriculum on the basis of solving practical engineering problems. Next, we need to clarify the elements of the engineering education mechanism contained in the scientific research capability of engineers, and organize these elements of scientific research and all the mechanism elements according to the rules and requirements of engineering education, so as to keep promoting the development of engineering education.

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