Research on the Element Structure and Cultivation of Engineers' General Ability in the Chinese Context

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Research on the Cultivation of Engineers' General Ability —Base on Empirical Research on Industry

Introduction

Engineering and Technology have played an important role in the economic and social development, which are indispensable forces for human beings to seek a higher level of life. And the ability of engineers directly determines their related indispensable and competences. From the current point of view, there are still some problems about the ability of engineers [1]. The weak of general ability is one of the important aspects. According to the existing researches and surveys, current engineers are commonly short of the communication skills, interdisciplinary knowledge, etc. [2][3] And under the premise of the rapid technological development and more severe human challenges in the future, it requires engineers to acquire a wider range of general abilities beyond professional knowledge, such as the ability of lifelong learning to adapt to future changes, the ability to participate in global competition, etc.

Therefore, the main research question of this paper is to study the general ability of future engineers and how to cultivate these skills more systematically in the Chinese context. This research firstly analyzes the current research and practice on engineers' general ability and its cultivation through literature review and case studies. Then, based on the existing research and practice, the questionnaire is designed and distributed to the industry. Through the factor analysis method, the components of engineers' general ability and general ability cultivation are obtained, and the differences between the factors are discussed.

Literature Review and Case Study

The elements and cultivation of engineers' general ability will be reviewed both in theory and practice level through literature review and case study, which will provide enlightenment and reference for the item design of the follow-up questionnaire of this study.

General Ability of Engineers

Many scholars have conducted the deep researches on the "general abilities" and most of them unscramble it from the understanding of "general education". Xie Guihong et al proposed that "The general education is liberal education for wide knowledge and elegance. It aims to cultivate the spiritual personality for the high-quality innovative talents and shape their perfect mind. The essence of general education is personality education, that is, to cultivate students with tolerance, sincerity, stability, gregarious and enterprising, as well as the spirit and ability to pursue truth." [4] Li Manli thought that "The general education is committed to provide a kind of common and comprehensive basic education which is different with the profession education to all student. Such

way focuses on the integrated development of the students and repelling the excessive utilitarian and professional training. Through providing the universal knowledges and theories covering humanity, nature and social sciences to students, it targets to endow the students with a broad vision, profound intellectual foundations and independent thinking skills, capable of correct thinking, expression and judgment, having strong social adaptability. The highest purpose of general education is to cultivate talents with vision, integration, complete personality, and liberalism and beautiful and emotions." [5] From the above and other related researches, we can find that general ability is the abilities that students should be armed which contribute to acquire the successes in work and life besides the professional knowledge capabilities. [6][7].

From the practices of colleges and universities, lots of them have clearly proposed the extension of the general ability scope, or what kinds of general ability the university expects the students should be equipped. For example, *The General Education of the 21st Century* issued by University of California General Education Committee states that students should acquire basic knowledge, writing skills, critical thinking, mathematical reasoning, and bear the needed knowledge and thinking for citizenship and social responsibilities before receiving subject training. Harvard University proposes that students should have the following general abilities: mathematical ability, global vision, adaptability and exploration ability, decision making ability, thinking habits, critical thinking, communication skills, leadership and teamwork skills. Tsinghua University proposes that students should have the following general abilities: self-value formation, way of thinking, innovation awareness, cultural and artistic literacy, analytical skills, critical thinking, reading skills, teamwork skills, communication skills (written expression), communication skills (verbal expression), hands-on ability, energy saving awareness, scientific literacy, ability to express, learning ability, writing ability, lifelong learning ability.

However, it is a pity that no scholars have studied the connotation and component of the general ability of engineers, which is one of the important innovations of this research.

Cultivation of Engineer General Ability

For this part, it selects the liberal education courses from Chinese Tsinghua University, Fudan University, Beijing Normal University, American Harvard University, Stanford University, Columbia University and University of Chicago as the case examination as well as detailly lists the directions of these liberal education courses. From the Table 1, we could find that these courses enjoy the large similarity and focus on expanding students' capabilities apart from the professional knowledge, including humanistic quality, international view, logic capability, mathematical thought, writing skill, communication ability and so on.

Table 1. The General Ability Training Courses of Some Chinese and American Universities

University	Course Direction
Tsinghua University	History and Culture, Language and Literature, Philosophy and Life, Technology and Society, Contemporary China and the World, Art and Aesthetics, Law, Economics and Management, Science and Technology
Fudan University	Classical and Cultural Heritage, Philosophical Wisdom and Critical Thinking, Civilized Dialogue and World Vision, Social Research and Contemporary China, Scientific Exploration and Technological Innovation, Ecological Environment and Life Care, Artistic Creation and Aesthetic Experience
Beijing Normal University	Homeland Feelings and Value Ideals, International Vision and Civilization Dialogue, Classic Study and Cultural Heritage, Mathematical Foundation and Scientific Literacy, Artistic Appreciation and Aesthetic Experience, Social Development and Civic Responsibility
Harvard University	Aesthetics, culture and Interpretation, History, Society, Individual, Social Science and Technology, Ethics and Citizenship, Art and Humanities, Social Sciences, Natural Sciences or Engineering and Applied Sciences, Empirical and Mathematical Reasoning
Stanford University	Thinking and Behavior Methods, Effective Thinking, Writing and Rhetoric, Language
Columbia University	Contemporary Civilization, Literary Humanities, University Writing, Art and Humanities, Music and Humanities, Science Frontier, Science Compulsory, Global Core Compulsory, Foreign Language Compulsory, Sports Compulsory
Chicago University	Humanities, Foreign Languages, Mathematical Sciences, Natural Sciences, Social Sciences, Civilized Studies

Research Design

Definition and Measurement of Variables

The definition of an engineer's general ability in this study means that the engineer shall master the other non-professional abilities which are good to their work and life besides the professional and skills on this basis, with referring to the current theoretical researches and colleges and universities' practices, a total of 34 items were designed to measure the general ability of engineers (referring to Table 2). The samples were first asked to determine the importance of an item in the construction of engineers' general ability (importance level of general ability of engineers), then they shall be able to judge how the engineers in their companies performed in the item (actual performance level of general ability of engineers). In this way, we can judge whether the actual performance of the engineer has reached the expected level on a certain item.

We deem that the training of the general ability of engineers depends not only on the curriculum, but also on the coordination of other cultivation measures. Therefore, with referring to the current theoretical researches and colleges and universities' practices, this study designed 30 items including the curriculum to survey how the general ability of the engineers should be cultivated in

university.

Sample and Data Collection

The research objects of this study are engineers from industrial circle as well as the middle and senior managers from companies. This study adopts the online questionnaire system. The questionnaires were distributed from July 2018 to September 2018. 215 questionnaires were retrieved totally, including 201 valid questionnaires. And the questionnaire efficiency was 93.5%. The questionnaire is divided into three parts. For the first part, it is the basic conditions about the samples. About the second section, it narrates the general ability elements of engineer, involving 34 questions to measure the general ability. And in the third part, it is the University cultivation of engineers' general ability, including 30 questions about surveying the University cultivation.

Data Analysis

General Ability of Engineers

General Ability Factor Analysis

First of all, the method of factor analysis was used to analyze 34 items in order to explore the components of engineer's general ability.

The CITC value and coefficient of internal consistency - Cronbach α value are used to test the reliability of the items. According to the standard that the CITC value is greater than 0.5 and the Cronbach α value is greater than 0.7, all measurement items meet the reliability test requirements. After KMO and Barlett sphere examination, the KMO value of the sample data is 0.963, greater than 0.7 so that it suits to conduct the factor analysis; and the significance level of the Bartlett sphere test is 0.000, indicating that the data is correlated and suitable for factor analysis.

In this study, under the premise of maintaining all questions, the research conducted the exploratory factor analysis as well as gained the following results by repeated calculation. Firstly, through the first factor analysis, two predictive factors were obtained, named "political literacy" and "interdisciplinary knowledge". Then, the remaining variables were pressed ahead by the second factor analysis, and four predictive factors were obtained, which were named as "engineering ethics", "internationalization ability", "leadership and decision-making ability", "thinking and expression ability" respectively. Finally, the remaining variables were made by the third factor analysis. After deleting several items[①], four predictive factors are obtained, named as "independent thinking and learning ability", "work emotions and attitudes", "innovation and challenge ability", "self-value shaping ability", as shown in Table 2.

[①] The deleted items are as follows: being able to assist other members to work together; having curiosity; showing oneself or the team; being able to quickly master the knowledge and skills taught by experienced engineers; being able to perform tasks arranged by superiors or team leaders, etc.; being flexible when in trouble.

Table 2 Factor Analysis Results of Engineer General Ability

Measurement Item	Average Score of the Item (SD)	Factor Load	Factor Name
Having strong political awareness	3.15 (1.300)	0.871	Political Accomplishment
Having patriotism	3.77 (1.141)	0.679	
Deeply understanding and abiding by engineering ethics and law	4.42 (0.847)	0.831	Engineering Ethics
Enjoying strong social responsibilities in engineering activities	4.37 (0.860)	0.791	
Possessingc a scientific spirit and abiding by the basic laws of engineering technology	4.55 (0.794)	0.714	
Being aware of various risks in project implementation and subsequent operations, such as environment, safety, etc.	4.52 (0.810)	0.470	
Understanding the frontiers of professional-related interdisciplinary theories	4.08 (0.892)	0.499	Interdisciplinary Knowledge
Understanding professional-related economic management theories	3.77 (0.925)	0.803	
Understanding professional-related humanities and social sciences	3.56 (0.893)	0.815	
Being equipped with international perspective, understanding the global economy, history, geography, etc.	3.97 (0.951)	0.861	Internationalization Ability
Identifying and respecting international cultural differences and being able to conduct cross-cultural cooperation	4.11 (0.905)	0.513	
Being able to organize and lead a team to expand the work	4.39 (0.849)	0.719	Leadership and Decision-Making Ability
Managing one or more projects effectively	4.38 (0.835)	0.749	
Being able to make effective decisions in engineering and management	4.41 (0.819)	0.661	
Being equipped with good verbal ability	4.40 (0.825)	0.742	Thinking and Expression Ability
Being equipped with good written communication skills	4.39 (0.795)	0.775	
Being equipped with strong logical thinking ability	4.53 (0.802)	0.619	

Measurement Item	Average Score of the Item (SD)	Factor Load	Factor Name
Being equipped with ability to think independently	4.60 (0.768)	0.812	Independent Thinking and Learning Ability
Being able to continuously learn new knowledge and adapt to the changes of new technologies	4.59 (0.776)	0.692	
Being confident in work	4.36 (0.878)	0.779	Work Emotions And Attitudes
Being active in work	4.43 (0.827)	0.593	
Being able to lead a team at work	4.41 (0.819)	0.685	
Managing one's own and team emotions in the face of stress	4.34 (0.835)	0.542	
Having innovative thinking	4.31 (0.887)	0.678	Innovation and Challenge Ability
Having different views on the decision-making and planning of the superiors	4.18 (0.913)	0.788	
Willing to accept challenges and get in touch with new things	4.21 (0.891)	0.681	
Being equipped with a persevering will	4.35 (0.889)	0.760	Self-Value Shaping Ability
Having one's own life planning and development goals	4.39 (0.863)	0.582	

Through above researches, this paper proposes 10 universal abilities of engineers, including political accomplishment, engineering ethnics, interdisciplinary knowledge, internationalization competence, leading and decision-making capability, thinking and expression ability, independent thinking and learning ability, work emotions and attitudes, innovation and challenge ability and self-value shaping ability.

The Differences Between Importance Level and Actual Performance Level of General Ability of Engineers

At the beginning, I want to indicate that the below mentioned importance degree means the ability importance to the engineer which is recognized by the industrial circle. And its actual performance level states that the professional personnel's evaluation on the actual performance of the engineers. Through comparing the two items, we could find the gap between the importance degree and actual performance level of general abilities.

From the perspective of the importance degree, 8 of 10 general abilities are scored above 4.0 (see table 3) from the industry's evaluation, indicating that these 8 general abilities are relatively important, and the five highest scores are successively the independent thinking and learning ability, engineering ethics, thinking and expression ability, leadership and decision-making ability, work emotions and attitudes. At the same time, it can be found that the scores of political literacy

and interdisciplinary knowledge are below 4.0, indicating that these two general abilities are relatively unimportant.

Viewing from the actual performance level, the scores of 10 general abilities are all lower than 4.0, and the five items with relatively high scores are successively the engineering ethics, thinking and expression ability, work emotions and attitudes, independent thinking and learning ability, and self-value shaping ability. The two items with relatively low scores are still the political literacy and interdisciplinary knowledge.

By comparing the actual performance level and importance level, the difference values (actual performance level-importance degree) acre all negative. Except for political literacy, the absolute difference values of other items are close to or exceed 0.5, which indicates that the industrial circle deems the actual performance of engineering personnel in 10 general abilities is lower than the expected level of importance, and the gap is large.

It is particularly worth noting that the industrial circle deems that the important degree of political accomplishment is 3.46, the actual performance level of engineer is 3.32, the difference value is -0.142. And the importance degree of interdisciplinary knowledge is 3.80, the actual performance level of engineer is 3.18 and their difference value is -0.622. It demonstrates that from the aspect of the industrial circle, the engineer importance degree about the political accomplishment and interdisciplinary knowledge are relatively low and the actual performance level is also relatively low. For the above situation, it might because these samples have worked for more than a decade. More than a decade ago, Chinese engineering education pay less attention to the political accomplishments and interdisciplinary knowledge which make the samples lay less emphasis on the latter work.

Table 3. The Difference Values between the Importance Degree and Actual Performance Level

	Importance Level	Actual Performance Level	Difference (Actual Performance Level-Importance Level）
Political Literacy	3.46	3.32	-0.142
Engineering Ethics	4.47	3.98	-0.485
Interdisciplinary Knowledge	3.80	3.18	-0.622
Internationalization Ability	4.04	3.53	-0.508
Leadership and Decision-Making Ability	4.39	3.67	-0.721
Thinking and Expression Ability	4.44	3.86	-0.579
Independent Thinking and Learning Ability	4.59	3.75	-0.849
Work Emotions and Attitudes	4.39	3.78	-0.608
Innovation and Challenge Ability	4.23	3.56	-0.667
Self-Value Shaping Ability	4.37	3.70	-0.670

	Importance Level	Actual Performance Level	Difference (Actual Performance Level-Importance Level）
Average Value	4.22	3.63	-0.590

University Cultivation of Engineer General Ability

Factor Analysis of University Cultivation

The method of factor analysis was used in the same way as the previous section. All of the 30 measurement items have a CITC value greater than 0.5 and a Cronbach α value greater than 0.7, which meets the reliability test requirements. The KMO value of the sample data is 0.891, greater than 0.7, and the significance level of the Bartlett sphere test is 0.000, indicating that the data is correlated and suitable for factor analysis.

The research adopts the method which is partially same with the part of "Factor Analysis of General Ability" to conduct the factor analysis. The CITC and Cronbach α value of all measurement questions about "University Cultivation" are respectively larger than 0.5 and 0.7 which cater to the credit analysis requirements. The KMO value of sample data is 0.891 which is larger than 0.7 and suits to conduct the factor analysis. The significance level of Bartlett sphere experience is 0.000 which shows the relevance among the data and suits to the factor analysis.

In this study, under the premise of maintaining all questions, the research conducted the exploratory factor analysis as well as gained the following results by repeated calculation. Through the first factor analysis, it gained the four predictive factors, named "Political literacy and responsibility courses", "humanities and art courses", "Social management and self-development courses" and "Teaching supports". Then, the remaining questions were conducted by the second factor analysis, and obtained the three predictive factors, which were named as "Interdisciplinary and ethical courses", "Learning methods" and "Teaching methods", as shown in Table 4.

Table 4 The Factor Analysis Results about the University Cultivation of Engineer General Ability

Measurement Items	Average Score of The Item (SD)	Factor Load	Factor Name
Political theory course	3.29 （1.073）	0.743	Political literacy and responsibility Courses
Patriotism and personal value course	3.64 （1.058）	0.682	
Social development and civic responsibility course	3.83 （0.915）	0.575	
History and culture course	3.52 （0.817）	0.733	Humanities and art Courses
Language and literature course	3.76 （0.774）	0.589	

Measurement Items	Average Score of The Item (SD)	Factor Load	Factor Name
Philosophy and life course	3.58 （0.929）	0.779	
Contemporary China and the world course	3.46 （0.863）	0.717	
Art and aesthetic course	3.40 （0.939）	0.782	
Law course	3.77 （0.792）	0.759	Social management and self-development Course
Economics and management course	3.69 （0.773）	0.753	
Career planning course	4.03 （0.847）	0.519	
Interdisciplinary engineering foundation and professional courses	3.96 （0.630）	0.806	Interdisciplinary and ethical Courses
Engineering ethics course	3.93 （0.790）	0.697	
Industrial internship	4.28 （0.800）	0.756	Learning Methods
Social practice	4.28 （0.828）	0.802	
University club activities	3.46 （0.907）	0.685	
Science and technology innovation competitions	3.82 （0.888）	0.624	
Mutual learning between students	3.83 （0.811）	0.695	
Interactive discussion between teacher and students	4.15 （0.699）	0.791	Teaching Methods
Interdisciplinary teaching	3.96 （0.770）	0.789	
Teachers with engineering practice carry out teaching	4.45 （0.611）	0.700	
Business management personnel carry out teaching	4.45 （0.688）	0.696	
Scholars from both inside and outside the university regularly conduct lectures on humanities and social sciences	3.97 （0.810）	0.740	
University leaders have high humanistic qualities	4.26 （0.765）	0.745	Teaching Supports
University leaders attach importance to the cultivation of general ability	4.46 （0.629）	0.674	
University and departments can strongly guide and support	4.26 （0.671）	0.668	
University sets up specialized institutions to engage in general education reform and research.	4.01 （0.783）	0.606	
The full-time engineering faculty has high humanistic qualities	4.04 （0.722）	0.757	
University conducts relevant general education to full-time faculty	4.15 （0.728）	0.835	
Requiring teachers to integrate general education into the teaching of professional courses	4.15 （0.707）	0.797	

The Comparison on the Important Degree of Different Factor of University Cultivation

According to Figure 1, the industrial circle deems that the above seven parts are the important degree of cultivating the general abilities of engineers. It can be found from Figure 1 that, from the perspective of industry, the most important aspects of cultivating engineers' general abilities are “teaching supports” and “teaching methods”, and relatively unimportant aspects are “humanities and art courses” and “political literacy and responsibility courses." This also explains to a certain extent that the core of cultivating engineers' general abilities is to improve the general ability through different situations of training rather than to learn theoretical knowledge from the classroom; improve the general ability thorough different situation or perform the general abilities as the skills rather than the knowledge. It shall be obtained through continuous practice.

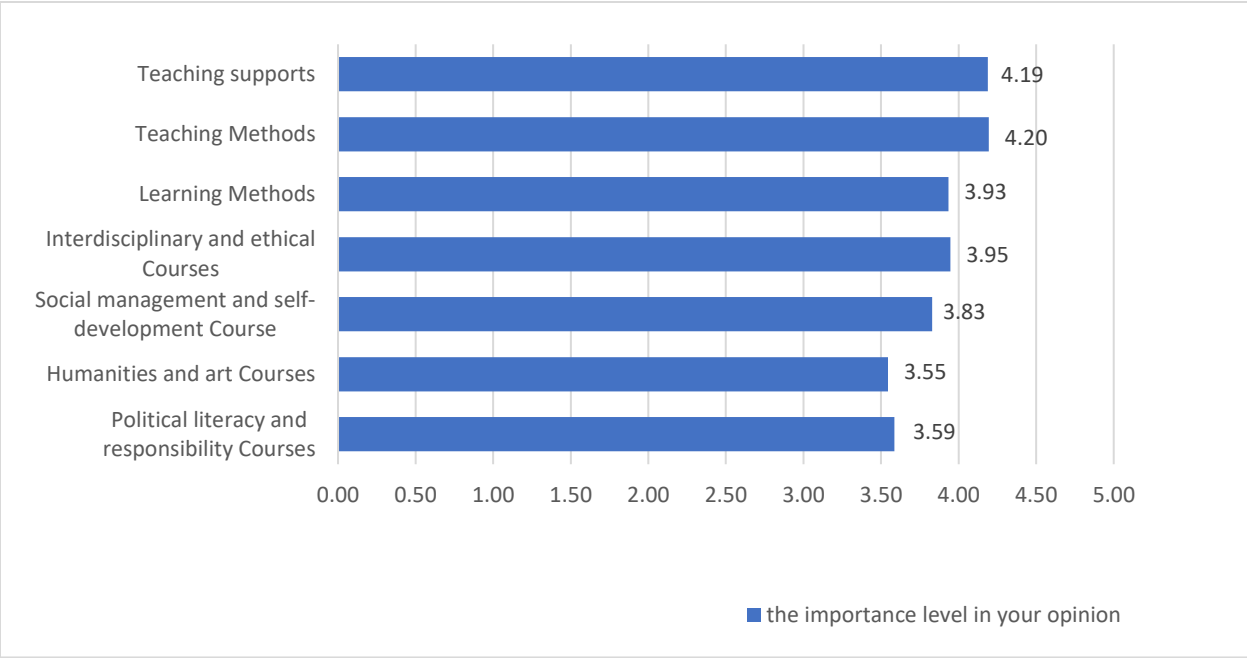

Figure 1 The Scores of Seven Cultivation Parts

Conclusion

The general ability of engineers plays an increasingly important role in their life and work. Therefore, it is very necessary to conduct an in-depth study on the components of the engineer general ability and how to cultivate their general ability. Through the quantitative research methods, this study finds that the general ability of engineers consists of 10 elements (see table 2), and the cultivation of general ability of engineers consists of 7 elements (see table 4). In terms of elements of general ability, from the research, we find that the actual performance level of engineers on each element is lower than expected. Therefore, all of the elements of general ability must be strengthened in the future. From the perspective of general ability cultivation elements, this study figures that the “teaching supports” and “teaching methods” are the most important elements for

training the general ability, which enlightens us that the general ability is more like a skill than knowledge. Therefore, universities need to develop students' general ability through innovative teaching methods and teaching activities.

The pity thing is that the paper does not consider the industrial circle demand in the cultivation. It is expected to take it into consideration as it works to form the prefect researches.

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