

**Assessing Chinese Engineering Graduates' Abilities for
Problem-Solving, Scientific Discovery and
Technological Innovation — from a Professoriate Perspective**

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Abstract

For the past two decades, there has been a strong national drive in China for scientific discovery and technological innovations in order to catch up with the developed countries of the world. Achieving such ambitious goals requires a whole new generation of scientists and engineers who are solid in academic foundations, capable of problem-solving, proficient in acquiring the latest information on scientific and technological developments, and full of courageous spirit for scientific and technological innovations. Does Chinese engineering education adequately prepare its students to undertake such historical endeavors? Based on an empirical survey of university faculty members, this study has investigated Chinese engineering graduates' levels in

(1) academic abilities, (2) communication skills, (3) engineering experiences, (4) potentials for scientific and technological innovation and invention. It has been found that the majority of faculty members is satisfied with the above four areas of abilities of their students, and are confident in their engineering success.

Introduction

Since the end of so called “Cultural Revolution” in China in 1977, there has been a strong national push for scientific discoveries and technological innovations to catch up with the developed countries of the world, and to meet the challenges of the next millennium. During the past two decades, China has experienced unprecedented scientific and technological growth and maturity mostly due to her new “open door” policy that has brought in billions of dollars of technological and scientific investment and facilities from the West. The most noteworthy examples are telecommunications, material science, aerospace technology, generic research, pharmaceutical industry, and information technology. (For detailed examples of US-China joint ventures, see: <http://www.boeing.com/companyoffices/aboutus/Boechina97.html>, for Boeing in China and http://www.sichuan-china.com/sichuan-china/scpages/IA_29.HTM for Motorola in China, <http://china.com/> for China.Com, the Internet gateway to China).

In spite of its fast scientific and technological achievements in recent years, there is still a substantial distance between China and other industrial nations, such as America, with respect to overall scientific and technological levels. The distance is even wider with regard to new scientific and technological developments. How can China reduce such distances within the shortest possible time?

According to the influential Bush Report (1945) that reshaped America’s engineering education after World War II, a nation’s scientific and technological advancements depend, to a large extent, on the capabilities of its scientists and engineers to absorb the latest scientific and technological information and knowledge, to find solutions to problems, and to carry out research, to experiment, and to realize new scientific and technological frontiers. To achieve such national capabilities requires all engineering educators to instill the spirits as well as the capabilities of problem-solving and innovation early among engineering students.

Today, even a cursory survey of the curriculum of virtually all engineering schools in America would reveal ample emphases on developing students’ skills of problem-solving, research and inventions (Gorman, Richard, Scherer & Kagiwada, 1995; Keating & Stanford, 1999; See <http://www.physics.umn.edu/groups/physed/Research/CGPS/CGPSintro.htm> for cooperative group problem solving of University of Minnesota Physics Education Research and Development). Such emphases are also highlighted by the mission statement of American Society of Engineering Education (See <http://www.asee.org/welcome/html/mission.htm>).

Chinese engineering education also has a long tradition of emphasizing students’ fundamental skills as well as abilities for problem-solving and scientific discovery. However, there seems to be some subtle differences between Chinese and American approaches. For example, in America, it is common for engineering professors to introduce real-world problems for students to work on, either independently or collectively, from the early stages of engineering education.

When students work on realistic engineering projects, they would go through a complete cycle of product development: literature search, design, implementation, data acquisition, analyses, efficiency assessment, calibration, reliability testing, modification, prototyping, report writing and presentation, and so on. Such a process helps students obtain invaluable real-world engineering experiences that cannot be realistically taught in a classroom (Ibeh, 1999).

Although it is not universally true in China, Chinese engineering curriculum tends to put more emphasis on basic skill development, such as math, engineering theories and principles. Students normally do not work on realistic engineering projects until they finish two or three years of engineering school. The reason for such a practice lies in an old Chinese philosophy that a solid foundation leads to infallible construction.

However, today's world has entered an era of information explosion and rapid technological advances (Morgan, Reid & Wolf, 1998). Today's knowledge may soon become obsolete. In order for modern engineers to be successful, they not only have to have a solid academic foundation, but also a wide spectrum of new skills, such as engineering leadership, organization, computer programming proficiency, communication, and rapid adaptation to changes, and the spirits for innovation and invention. Does Chinese engineering education sufficiently emphasize such new needs and abilities so that China's science and engineering students can meet the challenges of the next century? The purpose of this pilot study is to find out, from the engineering educators' perspective, how prepared Chinese engineering graduates are with respect to their abilities for problem solving, innovation and invention.

Research Methodology and Instrument

In order to answer the above research question, a survey, entitled "Assessing New College Graduate Engineers' Abilities for Problem Solving, Research and Innovation", was constructed to collect the opinions of university faculty members on their engineering graduates' abilities. Inspired by the summary report by Morgan, Reid and Wulf (1998), this survey consisted of five major parts. The content of this paper is based on the first three parts of the survey (See Attached 1 for the abbreviated version of the survey).

Part I was designed to gather information about faculty members' biographical information as well as their schools. Part II evaluated the curricular emphases on eight essential skills, ranging from problem solving to new product development. Part III was further divided into four areas of evaluation: (1) academic foundations, (2) communication skills, and (3) engineering experiences, (4) information acquisition, innovation and invention. All the answers were framed in a version of a five-level Likert scale (Likert, 1932) ranging from "1" to "5", with "1" as the lowest level, "3" as the middle level, and "5" as the highest level of ratings.

The survey was first drafted in English, and then translated into Chinese. The consistency between the Chinese and English versions was checked by the four authors, and then further refined by a fifth Ph.D. Chinese language professor who was also proficient in English language. The survey was finally administered in Chinese.

Research Subjects

A total of 75 surveys were sent out to six universities in a central south province of China in August, 1999. Results were obtained from 64 faculty members with incomplete answers from only one survey participant. Among the 64 faculty members surveyed, there were 9 lecturers, 36 associate professors, 9 professors, and 9 other staff members. Although the 64 faculty members spanned over 58 engineering specialties, 23 of them worked in the general field of mechanical engineering; 11, in electric engineering; 11, in applied physics; 5, in computer science; 10, in civil engineering; and 4, in other disciplines. Forty-one faculty members were male, while 22, female. Their university teaching experiences ranged from 1.5 to 40 years with an average of about 16 years.

Although the sample size was less than ideal and the sampling method was, by no means, completely random, all possible effort was made to ensure complete anonymousness, accuracy and impartiality of results, as well as the widest possible coverage of the engineering schools in the central south province of China. No participant was hinted in any way that the results of this survey would be reported at a professional conference. All the 64 survey participants seemed to be enthusiastic and supportive of this study. The entire study was completely funded by the four authors privately, and there was no sponsorship from any other source.

Analyses and Results

Assessing Curricular Emphases:

The essence of engineering lies in finding solutions to problems, improving existing technology, and creating new technological frontiers. Does Chinese engineering curriculum adequately address these issues? This concern was answered by the first question in the survey: “How necessary is it for your engineering curriculum to develop students’ abilities in (1) real-world problem solving; (2) technological innovation, (3) scientific and technological invention, (4) new product development, (5) educating on the latest technological information in the field, (6) overall engineering competence, (7) carrying out engineering projects, (8) students’ hands-on activities?” The faculty members were asked to choose one of the five ratings: 1= rarely necessary, 2 = slightly necessary, 3 = somewhat necessary, 4 = necessary, 5 = extremely necessary. Table 1 summarizes the frequencies of the choices as well as the average ratings of the survey participants.

Table 1: Choice and Rating Summary on Curricular Emphases:

<i>Questions</i>	<i>Choice Frequency</i>					<i>Average Ratings</i>
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	
Real-world problem solving	0	0	0	26	37	4.52
Technological innovation	0	3	19	33	8	3.67
Scientific and technological invention	0	1	9	25	28	4.20
New product development	0	2	16	36	9	3.77
Educating on the latest technological information in the field	0	0	11	31	22	4.17
Overall engineering competence	0	1	6	28	29	4.33
Carrying out engineering projects	0	1	23	34	6	3.70
Students' hands-on activities	0	1	3	28	31	4.34

Note: Some row frequencies may not add up to 64 due to missing data.

According to Table 1, more faculty members considered the abilities 1, 3, 5, 6 and 8 more necessary than abilities 2, 4, and 7. The average ratings for the first set of abilities range from 4.17 to 4.52, while the average ratings for the second set of abilities vary between 3.67 and 3.77. The small rating difference between these two sets of abilities may be due to the fact that the former set, such as problem solving and hands-on activities, are more concerned with engineering competence that students must develop in school. The latter set of abilities, such as technological invention and conducting engineering projects, are more relevant to career achievements after the students graduate and become employed. Of the eight skills, “real-world problem solving” was considered most necessary, while “carrying out engineering projects”, the least necessary. In summary, the majority of faculty members considered all of the eight areas of abilities either necessary or extremely necessary.

The choice and rating configurations reported in Table 1 seem to have confirmed the old Chinese philosophy described earlier – foundation first, practicality second, although not to ignore the latter. The ability of problem-solving has been shown to be the center of Chinese engineering curriculum. According to conversations with several Chinese professors who have visited or done research in American universities, problem-solving skills are more often cultivated in application questions, and term papers or projects are less often assigned to students. This is especially true in early stages of engineering education. However, what is consistently emphasized in Chinese engineering education is students' true academic abilities and the mastery of all the fundamentals in all subjects that are taught. This is why examinations are used more often than projects to evaluate achievement, because examinations leave little room for students to hide their academic deficiencies.

The above findings on Chinese engineering educational emphases and approaches coincide with the positions held by William Power, vice president for research at Ford Motor Company, who encouraged engineering schools to “continue to focus on fundamentals and hands-on capabilities” (Morgan, Reid & Wulf, 1998). However, as advised by Power, caution should be exercised to prevent current engineering curriculum from becoming stagnant. The authors would like to call upon all Chinese engineering educators to stay abreast of the most recent scientific

and technological developments and trends in the world, and constantly modernize their curriculum to offer the best to students.

Assessing Students' Academic Abilities:

Given the curricular emphases as summarized in the previous section, how are the academic abilities of engineering students by the time they graduate from engineering school? Five areas of abilities that are essential to success in modern engineering were assessed: (1) mathematical aptitude for solving real-world problem, (2) overall engineering knowledge foundation, (3) overall engineering hands-on competence, (4) proficiency in computer programming, (5) foreign language proficiency (any foreign language). These five abilities were evaluated at five levels: 1 = very low, 2 = low, 3 = OK, 4 = high, and 5 = very high, and the results are summarized in Table 2.

Table 2: Choice and Rating Summary on Academic Abilities:

<i>Questions</i>	<i>Choice Frequency</i>					<i>Average Ratings</i>
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	
Mathematical aptitude for solving real-world problems	0	6	33	22	3	3.34
Overall engineering knowledge foundation	0	4	18	35	7	3.70
Overall engineering hands-on competence	2	8	18	26	10	3.53
Proficiency in computer programming	0	3	28	27	5	3.50
Foreign language proficiency (any foreign language)	0	3	18	34	8	3.70

Note: Some row frequencies may not add up to 64 due to missing data.

As shown by Table 2, the majority of the faculty members considered their engineering graduates “OK” or “High” in these five academic abilities, while small numbers of other faculty members deemed their graduates either “Very High” or “Low”. The average ratings range from 3.34 to 3.70. In comparing the five abilities, engineering graduates were considered the strongest in foreign language proficiency, while in mathematical aptitude, the weakest. However, it can be concluded that the majority of faculty members were sufficiently satisfied with their graduates’ academic skills.

The fact that the 64 faculty members were most satisfied with the foreign language proficiency levels of Chinese engineering students is not surprising. English is the first foreign language required of virtually all engineering students in China. During the past two decades, major national efforts have been made to improve the English levels of all students in general. Nowadays, English is taught as early as the fourth grade in the elementary school in most metropolitan areas. In college, there is a mandatory two years of English courses for all science and engineering students. Since 1987, all science and engineering students must have passed four levels of nationally standardized English language proficiency certificate tests before they can graduate (See <http://www.sjtu.edu.cn/cet/> for College English Test program).

Assessing Communication Abilities:

In addition to academic competence, communication skills are indispensable for engineering success, especially in a modern information age. In many American engineering schools, engineering students are required to take a certain number of courses in writing, and oral communication classes are also recommended for them. Some engineering schools even offer creative classes that demonstrate the relationship between engineering design and communication (Shwom, Anderson, Olson, Kelso, & Colgate, 1999). Nowadays, in America, there is hardly any professional job advertisement that does not require effective communication skills.

In contrast, engineering students in China are seldom required to take courses in writing or any other liberal arts courses. Do Chinese engineering students possess adequate communication skills? This concern prompted the inclusion of four communication skills in the survey: (1) oral communication skills to convey and convince, (2) written communication skills to write research/engineering plans, (3) written communication skills to write research/engineering reports, (4) the ability to make presentations to superiors. As before, the rating scale ranges from “1=Very Low” to “5=Very High.” Table 3 summarizes the results.

Table 3: Choice and Rating Summary on Communication Skills:

<i>Questions</i>	<i>Choice Frequency</i>					<i>Average</i>
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>Rating</i>
Oral communication skills to convey and convince	0	2	21	34	7	3.72
Written communication skills to write research/engineering plans	0	7	17	35	5	3.59
Written communication skills to write research/engineering reports	0	5	19	31	9	3.69
Ability to make presentations to superiors	0	5	24	28	7	3.58

Note: Some row frequencies may not add up to 64 due to missing data.

About half of the faculty members considered their students “High” in the above four communication skills, about 30% of them deemed their students “OK”, and about 10% of them viewed their students either “Low” or “Very High.” The average ratings vary between 3.58 and 3.72. Of the four skills surveyed, Chinese engineering students were considered the best in their oral communication, and slightly less adequate in making presentations to superiors, which is understandable because most of them have not started working yet. It can be summarized that the majority of the faculty members thought of their graduates as sufficient in communication skills.

The fact that most faculty members considered their engineering students satisfactory and/or “High” in their communication skills in spite of the lack of formal communication training is somewhat surprising. Two factors might have contributed to such findings. The first factor may be the stringent selection criterion for Chinese language proficiency for all engineering students during the national college entrance examination process. Unlike American high school students

who take only one test, the SAT or ACT test, Chinese high school students must take, at least, seven separate tests on seven separate subjects: Chinese language, math, physics, chemistry, English, history, and political science. In addition to multiple choice items on Chinese grammar and vocabulary, examinees have to write essays as well as render their translations of ancient Chinese articles. Such vigorous examination process could have filtered out virtually all college applicants who may have a Chinese language deficiency.

The second factor is that in spite of the lack of formal communication courses, universities frequently, almost on an annual basis, hold oral speech and writing contests in both Chinese and English languages that require all levels of students to participate. Winners from university contests go on to higher provincial and national contests that are often broadcast live by provincial and national TV stations. All these activities could have compensated for the lack of formal communication training, thereby fostering the general consciousness and improvement of communication skills among engineering students in general.

Assessing Students' Engineering Experiences:

In addition to academic foundations and communication skills, success in engineering also depends on the amount of actual engineering knowledge and experience students acquire in school. In China, most engineering schools organize their students to periodically visit various factories from the second year of their engineering school. In their 3rd or 4th year, all engineering students are required to fulfill their practicum for 3-6 months in companies whose main business matches with the students' career objectives. Students work in and live near the companies just like regular company employees.

How much engineering experience do Chinese engineering students have by the time they graduate? This question is answered by the following five abilities in the survey: (1) routine technical operating abilities, (2) speed of acquiring new operating techniques (3) efficiency in mastering new operating techniques, (4) ability to solve new production problems, and (5) ability to actively conduct engineering experiments that may lead to new inventions and/or products. The results are summarized in Table 4.

Table 4: Choice and Rating Summary on Engineering experiences:

<i>Questions</i>	<i>Choice Frequency</i>					<i>Average Rating</i>
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	
Routine technical operating abilities	1	4	26	26	7	3.52
Speed of acquiring new operating techniques	2	0	19	35	8	3.72
Speed of mastering new operating techniques	2	4	28	26	4	3.39
Ability to solve new production problems	0	5	22	25	12	3.69
Ability to actively conduct engineering experiments that may lead to new inventions and/or products	1	4	21	30	8	3.63

Table 4 indicates that about 50% of the faculty members considered their students "High" in these five areas of engineering experiences, while close to 45% judged their students as "OK."

The average ratings ranged from 3.39 to 3.72. Of these five skills, the faculty members seemed to be most impressed with their students' ability to pick up new operating techniques. Since it takes time to master operational techniques, the average rating for the speed to master new operating techniques is slightly lower, which is not surprising. From Table 4, it can be concluded that the faculty members were satisfied with their students' engineering experiences.

Assessing Students' Abilities for Information Acquisition, Innovation, and Invention:

Given Chinese students' sound foundations in academic, communication and engineering skills, how are their abilities in acquiring the world's latest scientific and technological information, and in carrying out scientific and technological innovation? This issue is answered by the following five questions in the survey: (1) familiarity with the latest scientific/technological developments in their fields, (2) familiarity with the latest scientific/ technological trends in their fields, (3) ability to be informed on the world's latest scientific and technological developments in their fields, (4) ability to absorb the world's latest scientific and technological information, (5) ability to transfer the world's latest scientific and technological developments into new product designs. The results are summarized in Table 5:

Table 5: Choice and Rating Summary on Information Acquisition, Innovation and Invention:

<i>Questions</i>	<i>Choice Frequency</i>					<i>Average Rating</i>
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	
Familiarity with the latest scientific/technological developments in their fields	0	4	28	29	3	3.48
Familiarity with the latest scientific/ technological trends in their fields	1	7	24	27	5	3.44
Ability to be informed on the world's latest scientific and technological developments in their fields	2	5	16	29	12	3.69
Ability to absorb the world's latest scientific and technological information	0	6	14	25	19	3.89
Ability to transfer the world's latest scientific and technological developments into new product designs	2	7	21	24	10	3.52

Table 5 indicates that more than half of the faculty members considered their students "High" and/or "Very High" in the five abilities, while about 40% of them assessed the students to be, at least, "OK." Their average ratings ranged from 3.44 to 3.89. The highest rating belongs to students' ability to absorb the world's latest scientific and technological information. This finding coincides with the earlier finding of students' high foreign language proficiency which is essential to be informed on the latest technological developments. In summary, most faculty members were confident in the above five abilities of their students.

Conclusion

This study has systematically investigated the curricular emphases of Chinese engineering education as well as its students' abilities in academic foundations, communication skills, engineering experiences, and potentials for problem solving, scientific innovation and invention. It has been consistently found that university faculty members were, in general, sufficiently satisfied with their students' abilities and achievement in the above areas.

In recent years, one significant engineering curriculum reform has been taking place throughout China that will, in the authors' opinion, further enhance students' potentials for problem solving, technological innovation and invention. This reform stipulates wider and deeper interdisciplinary exchanges of knowledge and collaboration. Nowadays, more and more engineering schools have started to allow their students to take courses outside their departments (See <http://sun.ihep.ac.cn/uni/univs.html> for Chinese university listing and their curriculum information), and to allow students more freedom to shape their own career paths early on in their engineering education.

In the past, the division between engineering disciplines in China used to be so rigid that students were bound to the courses mostly within their own departments. Such a restrictive curriculum tended to create engineers with too similar capabilities. Among a group of engineering graduates, the situation tended to become "you know what I know and you do not know what I do not know."

On the other hand, inter-disciplinary exchange of knowledge and collaboration are well established academic practice among American university systems (Morgan, 1999). Projects are frequently carried out by students that draw on cooperation and expertise from various disciplines. However, at the present, the number of universities in China that have adopted this curriculum reform is still very small. It is hoped that more universities will adopt such inter-disciplinary curriculum reform so that more students can acquire a wider matrix of knowledge and abilities to complement one another in order to more efficiently resolve today's increasingly more complex engineering problems, and to make greater scientific achievements in the future.

The significance of this study lies in the fact that it is the first of its kind in China that directly evaluated engineering graduates' abilities for problem-solving, innovation and invention through a prefessoriate perspective. More research has been planned to assess employers' views of their new engineers' abilities so that comparisons can be made between educational and societal perspectives on the status and expectation of Chinese engineering education.

Appendix I

Assessing New College Graduate Engineers' Abilities for Problem Solving, Research and Innovation

(Academic Version: Code;_____)

Instructions: This survey is designed to obtain your evaluation of the problem-solving, research and innovation abilities of your fourth-year engineering students who are about to graduate. Please read the following questions carefully and answer them to your best ability. We truly value your input and thank you very much for your cooperation!

Part I: Information about yourself and your University:

1. What is your current official title in your University? _____
2. How long have you been teaching in your University? Please specify in years _____
3. What is your main official duty?
Administration ☐ Teaching ☐ Research ☐ Other: _____
4. What is your gender? ☐ Male ☐ Female
5. What is your age? Specify: _____
6. What kind of engineering school/department do you work in?
Mechanical ☐ Electronic/Electric ☐ Civil ☐ Computer ☐
Other: _____
7. What is your field of specialization? Specify: _____
8. What levels of students do you teach? You may check multiple entries below.
Undergraduate ☐ Masters ☐ Doctorate ☐ Other: _____
9. What is the status of your University? Please check the following:
State Key Uni. ☐ Ministry Key Uni. ☐ , Province Key Uni. ☐ Other:

10. How long has your University been in existence? _____ years.
11. On average, how many new engineering students does your School/Department graduate every year for the past 10 years? Please specify: _____

Part II: Curricular Emphases:

How necessary is it for your engineering curriculum to develop the following abilities?
(Note: 1 stands for the lowest rating, 5 for the highest rating)

1=Not Necessary 2=Rarely Necessary 3=Somewhat Necessary
4=Necessary 5=Extremely Necessary

Real-world problem solving	1	2	3	4	5
Technological innovation	1	2	3	4	5
Scientific and technological invention	1	2	3	4	5
New product development	1	2	3	4	5
Educating on the latest technological information in the field	1	2	3	4	5
Overall engineering competence	1	2	3	4	5
Carrying out engineering projects	1	2	3	4	5
Students' hands-on activities	1	2	3	4	5

Part III: Abilities of Engineering Graduates:

Please rate the following abilities of your new college engineering graduates. (Note: "1" stands for the lowest rating, "5" for the highest rating.)

1=Very Low 2=Low 3=OK 4=High 5=Very High

Academic Skills:

Mathematical aptitude for solving real-world problems	1	2	3	4	5
Overall engineering knowledge foundation	1	2	3	4	5
Overall engineering hands-on competence	1	2	3	4	5
Proficiency in computer programming	1	2	3	4	5
Foreign language proficiency (any foreign language)	1	2	3	4	5

Communication Skills:

Oral communication skills to convey and convince	1	2	3	4	5
Written communication skills to write research/engineering plans	1	2	3	4	5
Written communication skills to write research/engineering reports	1	2	3	4	5
Ability to make presentations to superiors	1	2	3	4	5

Engineering Experiences:

Routine technical operating abilities	1	2	3	4	5
Speed of acquiring new operating techniques	1	2	3	4	5
Speed of mastering new operating techniques	1	2	3	4	5
Ability to solve new production problems	1	2	3	4	5
Ability to actively conduct engineering experiments that may lead to new inventions and/or products	1	2	3	4	5

Information Acquisition, Innovation and Invention:

Familiarity with the latest scientific/technological developments in their fields	1	2	3	4	5
Familiarity with the latest scientific/ technological trends in their fields	1	2	3	4	5
Ability to be informed on the world's latest scientific and technological developments in their fields					
Ability to absorb the world's latest scientific and technological information	1	2	3	4	5
Ability to transfer the world's latest scientific and technological developments into new product designs	1	2	3	4	5

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(The remainder of the survey is omitted because its contents are not reported in this paper.)

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- URL: <http://www.physics.umn.edu/groups/phased/Research/CGPS/CGPSintro.htm>; University of Minnesota Physics Education Research and Development: Cooperative Group Problem Solving.

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