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Total Engineering Education: the Way to Shape our Future Leadership*

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In this article, the author highlights the economic, political and socio-cultural aspects of engineering education in the People's Republic of China. *Total Engineering Education* (TEE) is proposed as one method to shape the future leadership of the country. TEE encompasses the entire engineering education and profession preparation system, beginning from primary school programmes through to high school graduation, to post-secondary and graduate education. Critical issues of TEE implementation in China are discussed, including general engineering education for different levels and professions, cooperative education with industries, curriculum reform to address technology frontiers and globalisation requirements, innovation-oriented education, faculty development and so on.

INTRODUCTION

Charles Darwin once said that *It is not the strongest of the species that survives, nor the most intelligent, but the one most responsive to change*.

Although there are many definitions of *engineering*, it is widely acknowledged that Thomas Tredgold (1828), an English engineer and writer, gave an excellent definition: *Engineering is the art of directing the great sources of power in nature for the use and convenience of man.* Many recent documents make use of a similar definition; the American Society for Engineering Education (ASEE), for instance, defines engineering as the art of applying scientific and mathematical principles, experience, judgement and common sense to make things that benefit people, and engineering is the process of producing a technical product or system to meet a specific need. *Engineer* comes from the word engine, which means *to create*. Theodore von Karman probably best distinguishes the difference between scientists and the engineers: the engineer seeks to create what never was, while the scientist seeks to understand what is.

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It is now well recognised that engineering activities are the basis for the existence and development of the society. Engineering has changed the life, culture and thinking style of humankind. Civilisation entails the effective implementation of engineering know-how. This is evidenced from the early days of engineering activities, including the pyramids (~2500 BC, Egypt), King Goujian's bronze sword (~500 BC, China), the *Dujiangyan* water engineering system (~300 BC, China) and the Great Wall of China (206 BC, China). While ancient engineering was based on the experiences and intelligence of individuals, modern engineering is more based on science and technology. Multidisciplinarity and interdisciplinarity are becoming the rule rather than the exception. The changing nature of engineering has thus invoked changes in the mode of training for technical personnel.

The earlier engineering schools were established to educate civil engineers for building bridges, fortresses, roadways and canals. The first higher engineering school, Ecole des Ponts et Chaussée was founded in Paris, France, in 1747. Since then, other European countries followed the engineering education model and established new technical schools. For instance, the Technical University Vienna was founded in 1815, the Technical University Karlsruhe in 1825, and the Technical University Munich in 1827. In the USA, Rensselaer Polytechnic Institute in New York was founded in 1824. More disciplines in mechanical engineering were then taught at universities, which included steam engines (1782), locomotives (1812), railways (1822) and water pumps [1]. The institution of engineering education in the higher education system enhanced the civilisation of society. The high speed train, jumbo jet transport, automobile and cell phones have facilitated travel and communication. In retrospect, it can be concluded that modern civilisation would not have been possible without the contribution of engineering education.

At the dawn of the 21st Century, humankind stands poised between a resplendent past and uncertain future. The world is facing both rapid quantitative and qualitative changes. The former pertains to economic growth and technological innovations, while the latter to a new paradigm of an evolving society based on different values and ethos. A critical re-examination of the current engineering education system suggests a possible reformation of the current system. It is hoped that engineering education addresses the need for technological advancement in bioengineering, biotechnology and biomedical technology, information and communication technology, and miniaturisation (MEMS, nanotechnology and advanced materials). They should cover the growing complexity, multi-scale, uncertainty, multidisciplinary and interdisciplinary characteristics of engineered systems. It should also address the ecological environment that becomes worse day by day, the pressure of the population explosion, as well as the disequilibria in economic development that magnifies inequality in the distribution of wealth and increase poverty, which is a source of social instability.

Various strategies have been utilised in order to adapt to changes in many countries. In December 2001, the National Academy of Engineering sponsored a project related to the development of a vision for engineering and the work of engineers in 2020. In 2004, a report entitled *The Engineer of 2020* was published that gives an image of the future and the challenges it will present to engineering [2]. Shortly following the first report, a second one on educating the engineer of 2020 was also published, which provides full consideration on how engineering education should prepare for that future [3]. Early this year, the Association of American Universities (AAU) suggested that the USA faces new challenges to both security and prosperity: the danger to the national and homeland security posed by terrorism, the increasing competitive pressure from the growing economies of Asia and elsewhere, as well as the threat to the economic and national security posed by dependence upon Middle East oil. These challenges demand a dramatic and creative response. The national defence education and innovation initiative was then proposed to meet these challenges [4]. In European countries, much emphasis has been placed on the globalisation and unification of education systems [5]. The quality assurance of engineering education has been a major concern in the process of unification.

One should be aware that, in the course of the globalisation of economics and education, developing countries face more challenges than opportunities. The disadvantageous factors, such as the length of schooling being too long, educational costs are too high, etc, obstruct reform and the development of engineering education, and restrict the implementation and improvement of engineering education in developing countries.

In the present article, the author attempts to define in some detail the challenges that engineering education is facing currently in developing countries, particularly China. To deal with these challenges, the concept of Total Engineering Education (TEE) is proposed as a national strategy. TEE emphasises the following:

- Close cooperation with industry;
- Public awareness of engineering education;
- Multidisciplinary and interdisciplinary education;
- Interaction between campus-based research and education;
- Innovativeness as a key skill of students;
- Faculty development.

Although the article is mainly based on the environment of China, it may serve as an example for other developing countries.

CHALLENGES FACING ENGINEERING EDUCATION IN CHINA

Tradition Challenges

It is generally acknowledged that China was the world scientific centre before the 14th Century. The nation lost its technological leadership with the advent of the Ming Dynasty in the 14th Century because education was organised on the basis of examination (*keju*) for promoting administrative affairs with a hierarchical structure. Confucian thought that valued social harmony was questioned and debated. Such a biased education system lasted for a thousand years while technology and related engineering education in China were stymied. Technologies were regarded as a trivial skill, ie like *the trifling skill of a scribe* (*diao chong xiao ji*). The bureaucratic examination system ignored the value of technical skills and scientific endeavours.

Technical talents were downgraded by the government. In contrast, science and technology advanced in Europe and North America because of the establishment of technical universities, royal societies and scholarly publications; this was in addition to encouraging the establishment of social institutions to promote scientific and technical orientations. The shift of world scientific centre was witnessed following the trend: China (3^{rd}-13^{th} Centuries) → Italy (1540-1610) → UK (1660-1730) → France (1770-1830) → Germany (1810-1920) → USA (1920-). How this trend will be altered in this and/or the next century remains to be seen. Will China be revitalised? It is believed that the answer lies in engineering education.

Challenges to Building an Innovation-Oriented Country

Based on the belief that innovation is the core of a nation's competitiveness and the strategic motif of China's future science and technological development, reference can be made to the central government's identification of the major strategic tasks for building an innovation-oriented country earlier this year. The major issues are as follows:

- Adhere to innovation;
- Seek leapfrog development in key areas;
- Make breakthroughs in key technologies;
- Establish a common basis for technologies to meet urgent requirements in realising sustained and coordinated economic and social development;
- Enhance frontier technologies and basic research with a long-term perspective.

It is understood that the real core technologies cannot be purchased, but can only be achieved through innovation, which should be given priority in science and technology. Technology to foster energy resources, water resources and environmental protection should be ranked highly. Encouraging the innovation vitality of the entire society and turning scientific and technological achievements into productive forces are the prime ingredients to building an innovation-oriented country.

Talented people are the key to scientific innovation. A country should implement the strategy of building up its national strength with talented people in an all-rounded manner. It is obvious that education, particularly engineering education, should play a crucial role in cultivating the talents of its people. However, it should be pointed out that there is still a lack of strategic study concerning the reform of engineering education in comparison with other countries.

Technology Challenges

We are entering an era of rapid technology changes, which are reflected by a dramatic development of the frontiers of technology, and multidisciplinary and interdisciplinary technology trends. Together, chemical technology and mechanical engineering have facilitated the progress of process industries. The combination of mechanical engineering and electronics has enabled the development of mechatronics. There has also been an increase in multidisciplinary efforts to examine system challenges and envision approaches in a unified way, rather than through a hierarchical relationship. Chip-based technology, for example, has enabled many other technologies from microwave oven control (1 chip), automobile control (>10 chips) to airplane control (>hundreds chips). People encountered daily microprocessors from less than three in 1985, to 10 in 1990, and more than 50 after 1995. MEMS-based technology again elicits MEMS-based molecular diagnostics, biomaterials, biological-based computing and biomimetic robotics. Materials scientists are working increasingly with computer scientists and application engineers to develop biomedical materials for artificial tissues or produce reactive materials to facilitate active system control surfaces.

In the past, engineers were assigned specific design problems in order to solve specific problems. Today, science and engineering are moving strongly towards multidisciplinarity and integration. The multidisciplinary and interdisciplinary nature of technology is hence changing the skills required by engineers and scientists. Education and training must change to enable engineers and scientists to participate in multidisciplinary teams. Education should emphasise a breadth of disciplines to give at least a fundamental understanding of multiple disciplines [6].

The multidisciplinary and interdisciplinary nature of technology means a high density of knowledge integration in a single technology. This has been a great challenge for developing countries where the know-how and talents in a company are generally limited. This situation has caused much concern after the China National Mid- and Long-Term Science and Technology Plan was issued this year. It mentioned the key areas of development over the next 15 years, namely: energy, water and mine resources, environment, agriculture, manufacturing, transportation, information and modern services, population and health, urban planning and city development, public security and national defence, etc [7]. At the same time, biologic, information, new materials, advanced manufacturing, advanced energy, ocean, laser and aerospace technologies are also enlisted as technology frontiers in the Plan. All these areas and technologies are of a multidisciplinary and interdisciplinary nature. In order to achieve international competitiveness, it is imperative to develop an engineering education system that can deal with the above-mentioned aspects.

Economic Challenges

For more than two decades, China has been fully devoted to economic development. The rapid growth of the Chinese economy has made it possible to diminish poverty and starvation and allowed for the fast development of national infrastructures. The rapid growth of China's Gross Domestic Product (GDP) is illustrated in Figure 1. The growth rates (>8%) in recent years have been well above the world average. There is no doubt that education has contributed to the rapid development of China. The success of Chinese fundamental education (nine years compulsory education) has allowed many Chinese labourers to learn new skills quickly and very well, thereby accommodating changing industry requirements. Such attributes of Chinese workers have been one important factor that has attracted investments.

In a very recent report, Boston Consulting Group found that the top 100 companies from rapidly developing economies (RDE) have grown 10 times faster than the GDP of the USA, 24 times faster than Japan's and 34 times faster than Germany's. Among them, 44 are from China, 21 from India and 18 from Latin America [8]. However, the report also indicated that the emerging markets face many challenges. Most of the RDE-based companies are weak in technology innovation. Their general weakness is reflected in the small number of patents they hold. From 1999 through 2003, all the companies based in the five largest RDEs obtained only 3,900 US patents, whereas companies based in Japan and Germany obtained 166,000 and 54,000, respectively.

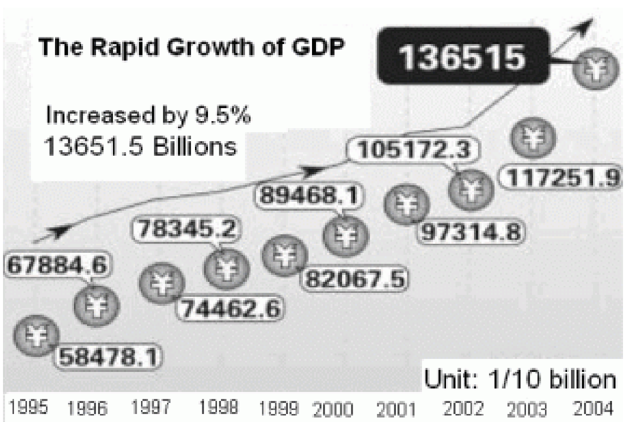

Figure 1: The growth of GDP in China.

In the case of China, this may be an indication of insufficient engineering and technology education. There are 900 million labourers in China. Among the 25 to 64 age group, 82% are below junior high school level (87 million are illiterate), 13% have senior high school education, with only 5% having received higher education. The ratio of the R&D force over the total population is only 0.084%, which is about $^1/_7$ that of the developing countries and $^1/_9$ that of the developed countries.

With the rapid development of high technology, such as nanotechnology/microtechnology, biotechnology, information technology, advanced manufacturing technology, as well as energy and resources related technologies, we are facing difficulty in providing higher educated workers for high tech enterprises. It is evident that China may lose its rapid economic growth and rise in competitiveness without its own high tech industry and self-dependent innovation ability. Thus, it is of particular importance to accelerate the reform and development of engineering education in a country like China so as to change the population pressure into advantageous human resources.

Resources and Environmental Challenges

Considering its large population, China is a country lacking resources. Table 1 gives a comparison of the major resource levels in China with those of the USA and the world [9]. However, the total level of energy consumption in China has increased by about 5% every year since the 1980s, which is about three times the increase rate of the world average. China's rapidly expanding transportation system and power consumption has placed increasing demands on oil, gas and coal. On the other hand, the energy consumption per GDP in China is significantly higher than that of many other countries. In 2002, for instance, the GDP energy intensity is 837 toe/million US$ for China, which is 3.19 times more than that of the world average level, and is 3.35, 5.65, 9.3 and 1.35 times more than that of the USA, European Union (EU), Japan and India, respectively (see Figure 2) [10]. It is obvious that there is plenty of room for energy conservation in China and it is also a big challenge for future engineers.

The increased awareness of environmental degradation and the depletion of non-renewable resources requires a sustainable development of Chinese society. Facing pressure from ecology, as well as resource and energy shortages, students should be educated to use lifecycle thinking in all engineering activities so as to conserve and improve natural ecosystems while also protecting human health and well-being by optimising the usages of all materials and energy sources.

Table 1: Chinese energy resources in comparison with the USA and world levels.

Country	Coal (10^8 tons)	Oil (10^8 tons)	Gas (10^{12} m^3)	Hydraulic Power (10^8 KWh/yr)	Uranium (10^3 tons)
China	1,145	33	1.7	1923	
USA	2,405	38	4.6	376	356.1
World total	10,439	141	142	1,4546	2,083.7
China average	95 tons	3 tons	1,416 m^3	1,603 kwh/yr	
USA average	962 tons	15 tons	11,8400 m^3	1,504 kwh/yr	
World average	209 tons	28 tons	28,400 m^3	2,909 kwh/yr	

Globalisation Challenges

Globalisation affects every aspect of engineering. William Wulf, President of the US National Academy of Engineering, stated the following:

> *Engineering is global, and engineering is done in a holistic business context. The engineer must design under constraints that include global cultural and business contexts – and so must understand them at a deep level. They too are new* fundamentals.

Nowadays, many companies employ engineers who are multinational, geographically distributed, conduct business globally and must deal with diverse business cultures and governmental regulations. Engineering designs need to take account of both local and global cultural perspectives (eg the environmental impact). Engineering teams are increasingly diverse in terms of culture and language, which is places an increased demand for engineers with international perspectives.

Nowadays, Chinese products have diffused into every corner of the world. It is not difficult to imagine that, in a few years, Chinese engineers will have to work in America to sell their computers, in African countries to help them in engineering construction, in Arabic countries to operate a refinery plant, and in European countries to undertake joint research on energy and environmental issues. They may also work in transnational companies, such as Bayer, BASF, IBM or Siemens or others with bases in China. Thus, Chinese engineering education must change to better prepare engineers to work in the global environment.

Challenges Due to the Expansion of Higher Education

The scale of higher education in China has greatly expanded since 1998, when the Chinese Government decided to implement the strategy of revitalising the nation with science and education. Figure 3 shows the change in the gross enrolment ratio of Chinese higher education. The total number of students studying at higher education institutions reached 23 millions by 2005 with a gross enrolment ratio of 21% and is predicted to reach 30 million by 2010 with a gross enrolment ratio of 25%. Nevertheless the gross enrolment ratio of Chinese higher education, when compared to other countries, is not yet high. For example, South Korea attained 68% (1997), Canada

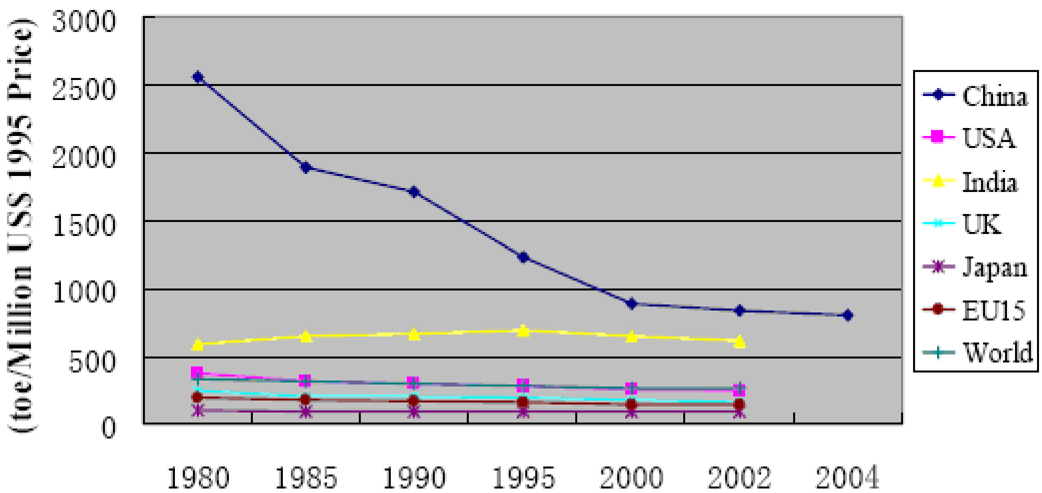

Figure 2: A comparison of international primary energy consumption per GDP.

88% (1995), Japan 45% (2002) and the USA 92% (1995).

However, in terms of the scale of engineering education, China can be considered as a huge country. In 2004, for instance, there were 4,376,167 engineering students studying in various universities and colleges, which constitute about 34% of the total number of university students, ie 13,334,969. This percentage is far more than any other discipline such as economics, law, literature, science and medicine, as illustrated in Figure 4. At the same time, there were 302,296 graduate students (Master's and doctoral candidates) studying engineering at universities, which is 38.84% of the total number of graduate students (779,408) [11]. The total output of engineering students is also much higher than any other country, such as the USA, UK, Germany and Japan. In many aspects, China can be proud of its engineering education for the successful cultivation of talented people nowadays in the leadership of the country, as well as the development of national defence and industries that secure the nation. On the other hand, in recent years, there have been growing numbers of people who have begun to raise embarrassing questions with university administrators about the quality of engineering education. More and more employers have complained about the lack of professional knowledge, as well as low levels of communication and teamwork skills, of engineering graduates. There has also been a tendency to decrease the number of engineering students due to the development of the tertiary industry.

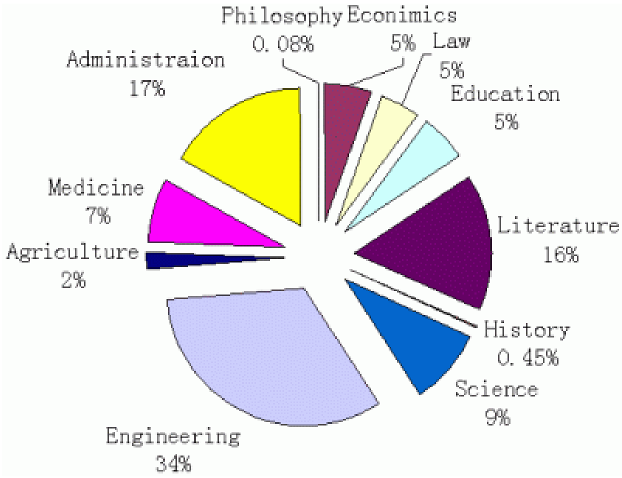

Figure 4: The proportion of college students studying in different disciplines in 2004 (total number of college students: 13,334,969) .

We are now in a dilemma of quantity and quality. It is believed that, as a country in the stage of industrialisation, it is of vital importance to have a strong engineering education of sufficient quantity. The problem is how to ensure a high quality of education with a large number of students.

COMPONENTS OF TOTAL ENGINEERING EDUCATION (TEE)

In order to meet these challenges and achieve national objectives in science and technology, we must make engineering education the nation's highest priority. The

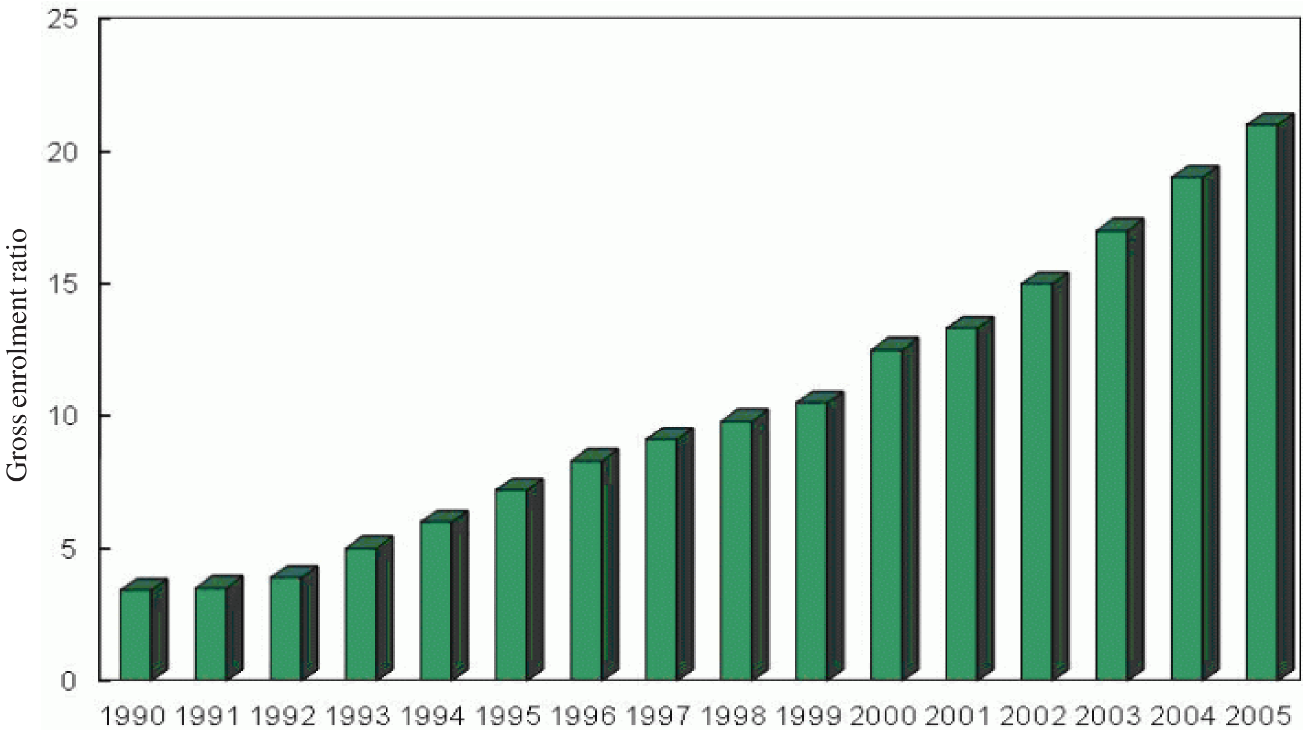

Figure 3: The gross enrolment ratio for Chinese higher education.

government, business and academia should be urged to develop and implement a new engineering education initiative aimed at meeting economic and security challenges on a long-term basis. The new engineering education paradigm must evolve so that it synthesises technology and the arts, educating students to make substantial contributions to a changing society, and is developmental, human-centred, environmentally sound and all-inclusive.

It is based on these considerations that the idea of Total Engineering Education (TEE) is proposed. Total Engineering Education encompasses the entire engineering education and profession preparation system, beginning from primary school programmes through to high school graduation, to post-secondary and graduate education. In this system, Chinese students for either engineering or non-engineering professions must have a basic understanding of engineering approaches, and have strong academic, technical and social skills, so that China can achieve strong competitiveness in the global economy of the 21st Century. TEE is committed to the total education of the individual as a social being and seeks to develop the whole person in terms of social and technical competences, as well as personal well-being. TEE should help to inform the public so that it understands and appreciates the impact of engineering on socio-cultural systems and recognises the engineering discipline's ability to address the world's complex and changing challenges.

It is the author's aspiration that, by implementing Total Engineering Education, engineers should be aware of the world so that they have the following characteristics:

- Be alert to global economic, political and technical trends;
- Have high ethical standards and a strong sense of professionalism;
- Be fundamentally sound and schooled in a selected discipline;
- Be technically broad with a strong level of confidence in a multidisciplinary;
- Be versatile and well-versed in problem solving, including applying engineering skills in non-traditional fields;
- Be able to communicate and collaborate in multifunctional teams, as well as be effective in leadership roles;
- Become a life-long learner so as to maintain professional and personal leadership.

The philosophy of TEE is generally true for most countries. In order to implement TEE in China, the following issues need to be emphasised.

General Engineering Education

Raising public awareness about science has, for the first time, been made an official part of China's national development strategy [3]. It is recognised that the population's lack of scientific knowledge has considerably hindered China's economic and social development. By 2010, China aims to have raised its population's understanding of science to the levels achieved in industrialised nations in the 1980s. And by 2020, it is hoped that scientific literacy will have risen to the same level as in the West today. It is believed that *engineering thinking* has become a critical foundation for human knowledge in the long-term evolution of humankind. Thus, it is of equal importance to raise people's understanding of engineering in the implementation of TEE. However, it is even more challenging to improve the nation's engineering literacy. About 900 million (72.8%) of the Chinese population live in the countryside and have limited access to modern machines and engineering constructions; as such, the general engineering education in primary schools and high schools in those areas may not be as effective as in the cities. Technically, modern distant education systems may also be of help.

It is hoped that university professors become more involved in the popularisation of engineering by writing introductory books about modern engineering and engineering disciplines. The engineering philosophy (or methodology) should be taught at different levels of education. At universities, non-engineering students should be encouraged or required to take general engineering courses. Students can benefit from their exposure to engineering design processes, problem-solving methods and the engineering decision-making process. Non-engineering students may also work in various industry companies after graduation.

Addressing the Technology Frontiers in Education

For many years in Chinese universities, there has been a distinct line between research faculty and teaching faculty. The lack of interaction between research and undergraduate education has been a major factor that has influenced the quality of education. This is reflected in aging text materials, lecture contents, course projects and graduation projects. As there is an increasing encouragement from governments and universities, more research professors now give lectures to undergraduates and more teaching faculty are involved in scientific research. This allows TEE to address more the science and technology frontiers.

The development of technology frontiers should be covered in engineering education, such as the development of the life sciences, information, new materials, advanced manufacturing, advanced energy, ocean, laser and aerospace technologies. This is important because engineering students are, or will be, involved in these developments and, by the end, it is engineering students who will push technology forward to a new frontier on the basis of the knowledge and skills they have gained from schools. As an example, the rapid development of nanotechnology and microtechnology has enabled many engineering applications. It should be of high priority to include them into education. As suggested by Sih, a blend of multi-scaling and mesomechanics in higher engineering education would help China's future engineers to design and manufacture new products based on nano/micro/meso-technologies [12]. In contrast to computational materials design, the prevalent industrial methods of materials development are based on an intrinsically slow and expensive process of trial-and-error empiricism [13]. The future of engineering education, therefore, ought to target the cutting edge of material design technology so as to move material R&D into a systems-based paradigm.

Addressing Globalisation in Education

Chinese people have generally viewed globalisation in a positive way. This is mostly due to the government's policy of opening up to the world. English education has been greatly emphasised at universities. It is encouraged that courses are delivered in a bilingual manner (mostly Chinese-English). However, most universities seemingly do not provide students with the whole concept of globalisation. The whole education programme should be redesigned in order to integrate globalisation elements into subjects. The following methods should be effective when implementing globalisation education:

- Increased exposure to international environments, such as study abroad programmes, academic exchanges (for faculty and students), internships abroad in multinational companies, university partnerships, cooperative degree programmes, joint research programmes, etc;
- Curriculum reform by learning more foreign languages, foreign history and culture, plus teamwork skills;
- Accreditation practices and industrial relations.

Some universities may start a global product development programme in cooperation with foreign universities and companies. The set-up of the global classroom based on Internet technology would be of help.

Government and business sectors should invest more money to allow universities to set up scholarship funds to support more overseas students studying in China. The infusion of international students will give Chinese university programmes a diversity and multiculturalism that expands graduates' experiences, adding value to their degrees. By attracting and retaining the best and brightest international students, scientists and engineers will surely increase China's competitiveness.

Innovation Education

In order to realise an innovation-oriented country, engineers of that country should have a strong sense of technology innovation. This should be given top priority in Chinese education. Chinese students should be motivated to become more innovative. Through an innovative education programme, students will always keep in mind the goal of creating something that is new and different from the previous one or to undertake something in a different manner. In order to achieve this goal, the connection between research and undergraduate education needs to be strengthened, including the expansion of undergraduate research opportunities. The university administrator should develop a healthy mechanism in order to ensure an increased level of interaction between campus-based research and education until it occurs spontaneously. The Ministry of Education has set a rule that every professor should give lectures to undergraduates. Further, every professor is encouraged to supervise a certain number of undergraduates to perform innovation-oriented research projects. Campus-based national research institutes and laboratories that are open to undergraduates are likewise encouraged. This new policy is now being implemented at East China University of Science and Technology (ECUST) in Shanghai, China.

Practice-Oriented Engineering Education

A recent survey indicated that 60.4% of respondents believed that current engineering education does not provide sufficient engineering training to students [14]. Engineering students generally lack an understanding of the importance of engineering design and problem-solving skills using comprehensive knowledge. They generally weigh science more than technology.

Starting a cooperative training programme with industry partners should be a desirable means to enhance students' understanding of engineering and improve their *hands-on* skills. As long as investment is possible, engineering schools should establish a comprehensive workshop to train students' design and manufacturing abilities.

Improving Teaching and Learning Styles

In traditional Chinese culture, teachers were highly valued and respected. This also influences Chinese education today. Most lectures and education programmes remain very teacher-centred, although there is increasing encouragement from governments and universities to adopt more innovative and student-centred styles of teaching and learning. It is easy to understand that students can no longer count on teachers, textbooks and lectures to tell them what they need to know to solve problems they are called upon to solve after they leave university and enter the world of work. The only resources that they have access to are themselves and their colleagues. If they are helped to become independent learners, developing and relying on their own reasoning ability rather than accepting information presented by others at face value, they can become interdependent learners, using the strength of the group to compensate for, and overcome, their own limitations. Students will then be equipped with the life-long learning skills that they will need for success throughout their postgraduate careers [15].

Most students enter college as dependent learners, relying on their instructors to present, organise and interpret knowledge. A significant part of our responsibility as instructors is to move students from a dependent stance to being independent learners who realise that all knowledge is not known and different points of view may come in shades of grey, rather than being either black or white, and that their task is to acquire knowledge from a variety of sources and subject it to their own critical evaluation. Students should be helped to go beyond independent learning to interdependent learning, recognising that all knowledge and attitudes must be viewed in the context that acquiring information from a variety of sources is more likely to lead to success than relying on a narrow range of sources and viewpoints, and that the peer group is a powerful learning resource. In working with others, students learn to recognise their own learning styles, strengths and weaknesses, and to take advantage of the synergy that comes from people with a diversity of backgrounds and abilities working together towards a common goal [16]. There are many active learning styles. Project-based learning is regarded as an effective learning style that increase students' levels of self-direction and motivation, and improve their research and problem-solving skills. The elicitation of a teaching style that was advocated by the great educator Confucius (551-479 BC) is still a good means to inspire and motivate students.

The Education of the Humanities, Arts and Social Sciences

In this world, there is always something, such as feeling and sympathy, which can hardly be measured by rules, balance or any precise scientific instrument. The humanities, arts, and social sciences are thus indispensable for the education of a full person of personal well-being, social competences, as well as long-term leadership. As indicated by Wilson:

> *Most of the issues that vex humanity daily cannot be solved without integrating knowledge from the natural science with that of the social sciences and humanities. Only fluency across the boundaries will provide a clear view of the world as it really is, not as seen through the lens of ideologies and religious dogmas or commanded by myopic response to immediate needs* [17].

There is no doubt that the Marxism and Mao Zedong's thoughts are essential to help students in China to establish a philosophy of analysing and understanding Chinese society. Students should also be encouraged to know the diversity of cultures and religions. They have to learn to appreciate others' culture so that they can work and cooperate with others in a multicultural environment.

Most Chinese students were born in a *one child only* family. They have been brought up in an examination-oriented educational system. Competitive pressure has left social responsibilities and moral education relatively ignored. Thus, the education of ethics and morality needs to be emphasised. Besides humanity and liberal education, engineering ethics and philosophy should also be taught as an imperative part of engineering courses.

Faculty Development

A university is recognised for its famous professors (scholars). Professors create the elements that lead to individual achievement, collective attainment, societal accomplishments, national leadership, as well as global security and stability. Without the substantial contribution from professors, all the above missions in the TEE system would not be possible. It is apparent that the total quality of the current faculty at Chinese universities is not high enough for little knowledge in engineering practice, as well as teaching. This is because they have been educated by the questionable education system, which provides very few chances to carry out engineering practice and teaching activities. As a result, the quality of students graduating from universities is not satisfactory. Only a few of the faculty have gained experience from studying abroad and/or have engineering work experiences.

In China, even in at a research university, not more than half of the faculty holds a doctoral degree [5]. This ratio is significantly lower than that of developed countries. Thus, it is very urgent to improve the quality of faculty at Chinese universities. The teaching assistant system in graduate schools needs to be reformed so as to allow more PhD students to be involved in teaching activities. Teacher training should be an integral part of Chinese PhD programmes, considering that most PhD students work in universities after graduation. The newly recruited young faculty are encouraged to work as a post-doctoral fellow in industry for one or two years in order to gain necessary industrial experiences.

SUMMARY

At the dawn of the 21st Century, the world is facing both quantitative and qualitative changes – quantitative in terms of technological innovations, population and economic growth, and qualitative in terms of a new paradigm of an evolving society governed by altogether different values and ethos. These changes pose many challenges. Although the current higher engineering education system in China has been very successful in educating talented people in the leadership of the nation, and in the development of national defence and industries that secure the nation, China is facing challenges from traditional thinking, governmental ambition to build an innovation-oriented country, fast changes in the frontiers of technology, the rapid growth of economics, limited resources and environmental degradation, globalisation, as well as a rapid expansion of the scale of engineering education.

In order to meet these challenges, the idea of Total Engineering Education (TEE) is proposed, which encompasses the entire engineering education and profession preparation system, beginning from children in primary school programmes through to high school graduation, and to post-secondary and graduate education. In this system, students for either engineering or non-engineering professions must have a basic understanding of engineering approaches, and have strong academic, technical and social skills in order for China to achieve a strong level of competitiveness in the global economy of the 21st Century. Critical issues in the implementation of TEE are discussed in the article, which include general engineering education at different levels and across different professions, educational reforms to address the technology frontiers and requirements from globalisation, innovation-oriented education, practice-oriented engineering education, the development of a methodology to improve learning and teaching styles, humanity and liberal arts education, and faculty development. There could be more fundamental issues for TEE to cover in other countries. Fortunately, the TEE paradigm is dynamic, developmental, human-centred and all-inclusive in which more solutions can be expected in the long run.

It should be pointed out that the current article does not consider the economic factors in the implementation of TEE. It is obvious that TEE requires more investment from the government and business sectors. But one thing that one has to bear in mind is that the education share of GDP in China is only around 3% these years, whereas the world average level is 5.1%. This implies that there must be more room left for educational development. Surely, we are in a century of hope!

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BIOGRAPHY

Shan-Tung Tu is a Vice President of East China University of Science and Technology (ECUST) in Shanghai, People's Republic of China, and a professor in the School of Mechanical Engineering. He received BSc degree in 1982 and PhD degree in 1988 from Nanjing Institute of Chemical Technology. From 1990 to 1993, he was invited as a guest scientist at the Department of Materials Technology, Royal Institute of Technology, Stockholm, Sweden. From 1993 to 2001, he worked as an associate professor, professor, Chairman of Mechanical Engineering, Dean of Undergraduate Education and Vice President of Nanjing University of Technology. He has been a *Cheung Kong* Chair Professor of Process Equipment authorised by the Chinese Education Ministry and has worked at the ECUST since 2001. He has lectured and given seminars in many countries, including Sweden, Korea, UK, Austria, Germany and Japan.

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