Chapter 4
Engineering and Development in Modern China: Challenges and Responses

Xiaonan Hong and Li Ma

Abstract Over the past several thousand years, China has made extensive and unique contributions to engineering and technological fields such as agriculture, food, textiles, architecture, metallurgy, ceramics, and medicine. In doing so, it has added significantly to the development of Chinese culture and all of human civilization. The Four Great Inventions of ancient Chinese people—papermaking, typography, gunpowder, and compass—are applied throughout the world. It is estimated that in 1820, China accounted for up to 30% of the world's GDP. However, for various reasons, Chinese engineering and technology stalled as China entered modern times and fell far behind developing Western countries. After being defeated by Western powers with their warships and cannons in the latter half of the nineteenth century, the secluded feudal Qing Dynasty began using some science and technology transferred from the West. These methods and machines provided a foundation for modern Chinese industry. But due to political corruption and recurring invasions by imperialist countries, China remained very weak in engineering, technology, and industry, falling behind developed countries in Europe and North America. This chapter analyzes the relationships between engineering and the development of modern Chinese society from the perspective of historical development. Based on a "challenge-response" model approach to theorizing the codeveloping processes of engineering and modern Chinese society, key engineering projects and representative engineers are selected for detailed analysis.

Keywords Engineering • Engineers • Modern China • Development • Chinese engineers

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X. Hong, Ph.D. (✉)
Programs of Philosophy of Science and Technology, Faculty of Humanities and Social Sciences, Dalian University of Technology, Dalian, Liaoning, People's Republic of China
e-mail: hxnharvard@yahoo.com.cn

L. Ma, M.A.
Foreign Language School, Dalian University of Technology, Dalian, Liaoning, People's Republic of China
e-mail: amethystada@yahoo.com.cn

S.H. Christensen et al. (eds.), *Engineering, Development and Philosophy*, Philosophy of Engineering and Technology 11, DOI 10.1007/978-94-007-5282-5_4,

Introduction

In the study of modern Chinese development, a prevalent explanation guiding development choice is referred to as the "challenge-response" theory. In the 1950s, John King Fairbank proposed the "impact (from the West)-response (from the East) theory," which became a very popular and controversial long-standing theory in American Sinology (Hong 2009, p. 255). The main problems with this theory are that it generalized and exaggerated the impact of Western invasions on China and overestimated the "superstable structure" of Chinese society, ignoring the dynamic role that Chinese society played during early modernization. After John King Fairbank put forward his "traditional-modern model" in the 1960s, Paul A. Cohen and others, students of Fairbank, proposed the "China-centered approach" in the 1970s. In this approach, they advocated seeking motivation for changes and advancement mainly from within Chinese society (Hong 2009, p. 255). This chapter will analyze the codeveloping processes of engineering and modern Chinese society based on the "challenge-response" model. Table 4.1 below provides an overview of the processes.

Premodernization Period (1840–1919): The Period of the Spread of Western Learning to the East, Saving and Survival

The major challenges for China in this period were the two Opium Wars (1839–1842 and 1856–1860) and the introduction of modern science and technology from the West. The response of Chinese intellectuals can be characterized as: saving and survival, saving and enlightenment.

In the West, natural science developed stage by stage from the Renaissance up to and through the Industrial Revolution. Western science was introduced into China over about two and a half centuries, starting with the Italian Jesuit missionary Matteo Ricci 's arrival in Guangdong Province in 1583. It continued through to the end of the Opium War in 1840. In 1601, Matteo Ricci's audience in Beijing with the Wanli Emperor of the Ming Dynasty occurred when modern science was emerging in Europe. Scientific achievements, such as Galileo's discoveries through experiments and mathematical methods, were spreading into China, hastened by European missionaries in China during the Wanli Era of the Ming Dynasty. During this time, China lost its dominant position as a civilization that leads scientific and technological developments. Instead, this became a period during which the spread of learning was from the West to the East.

During the 260 years of this period, modern science and technology developed rapidly in Europe and was gradually transferred to China. In contrast, China was declining in its comprehensive strength day by day, stubbornly sticking to its policy of seclusion. After two and a half centuries of cultural invasion, many Western

Table 4.1 Engineering and Development in Modern China

Historical period	Development as	Major views of communities
1840–1919 Premodernization—the period of the spread of Western learning to the East; salvation and survival	Saving and survival Learning from foreigners to compete with foreigners Chinese knowledge as the body, Western learning for uses	1913: Chinese Engineering Society 1915: Science Society of China 1918: Chinese Mechanical Engineering Society (CMES) *Celebrated engineer*: Zhan Tianyou (詹天佑) *Key projects*: Beijing-Shenyang Railway, Beijing-Zhangjiakou Railway
1919–1949 Change from traditional society to modern society	Saving and survival Saving outweighing enlightenment 1930s: modernization or Westernization	1919: science and democracy 1930s: modernization 1931: Chinese Institute of Engineers; the Period of the Westernization Movement *Celebrated engineers*: Hou Debang (侯德榜), Mao Yisheng (茅以升), etc. *Key project*: Qiantang River Bridge
1949–1978 Change from traditional society to modern society—the period of independent development	Marching toward science Learning from all countries Four Modernizations (agriculture, industry, national defense, science and technology)	*Celebrated engineers*: Li Siguang (李四光), Qian Sanqiang (钱三强), Qian Xuesen (钱学森), etc. *Key projects*: Qinghai-Tibet Highway, Wuhan Changjiang River Bridge, Nanjing Changjiang River Bridge, Guizhou-Guangxi Railway, Chengdu-Kunming Railway, Baoji-Chengdu Railway
1978–2011 Change from traditional society to modern society—the period of reform and opening up	Modernization Sustainable development 2003: scientific concept of development	1980s: Chinese character information processing and revolution of printing 1990s: strategy of invigorating the country through science, technology, and education Chinese Academy of Engineering, constructing an innovative country 2010: the Education and Training Program of Excellent Engineers *Key projects*: Qinghai-Tibet Railway, Beijing-Jiulong Railway, West-East Gas Transmission, West-East Electricity Transmission, North-South Coal Transport, Three Gorges Key Water-Control Project, Xiaolangdi Key Water Control Project, South-North Water Transfer, Linhuaigang Flood Control Project, Gezhouba Key Water Control Project, Longyangxia Hydraulic Power Plant, Qinshan Nuclear Power Plant, Qinling Tunnel, Hangzhou Bay Bridge, Beijing-Shanghai Express Railway

powers knew how frail and corrupt China was, so they resorted to force and invaded the country. Once a great military power, China was easily defeated in the Opium War by the United Kingdom, the first industrialized capitalist nation in the West. From that point on, China was "carved up" and exploited by other countries. China's failure in the First Opium War provoked some ardent patriots into exploring ways to save and strengthen the country. They ascribed China's failure to the advancement of Western technology, i.e.,

> Their steamships and telegraph are fast enough to travel a thousand li (one kilometer is two li) in a second; their weapons and military equipment are so refined that they are 100 times more effective; their artillery shells can overrun all fortifications, without being restricted by water or any passes; in several thousand years we have never met adversaries strong and formidable like them.
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> (Wu 1905, p. 45)

As the period 1583–1840 saw the spread of Western learning to the East, the time from China's failure in the Opium War in 1840 to its failure in the Sino-Japanese War in 1895 was the period of the Westernization Movement initiated by the government. At the beginning of this period, when China was forced to open five trading ports, Protestant missionaries came in large numbers, preaching the Gospel and introducing Western civilization's material, scientific, and cultural underpinnings to Chinese. The Qing government was still posing as the Celestial Empire, not eager to make any progress at all, so China was put in the passive position of having to import innovation, even via war. China was reduced to a semicolonial society inch by inch. A few men with insight such as Lin Zexu (林则徐), who proposed "learning from the adversaries to beat the adversaries," and Wei Yuan (魏源), who advocated "learning from foreigners to compete with foreigners," started to reflect on the general situation. After failing in the Second Opium War (1856–1860), the Qing government ascribed this failure to the advanced armament of the foreigners. A Westernization Faction developed in the gerontocratic group in which there were many important officials, such as Zeng Guofan (曾国藩), Li Hongzhang (李鸿章), and Zuo Zongtang (左宗棠), led by Yixin (奕䜣)—Prince Gong.

To tackle the Taiping Rebellion, the Westernization Faction introduced a series of policies such as *learning from foreigners, Westernization*, and *self-prosperity with Western-developed methods*, known historically as the "Westernization Movement" (Liu 2003, p. 42). The Westernization Faction initiated an epoch of saving the country by studying and promoting science and technology in China, enabling the transition from a traditional Chinese educational system to a modern educational system. Later, Liang Qichao (梁启超) put it clearly, "the essence of political reform is education, while to educate people we need to run more schools" (Liang 2002, p. 24), and so he believed that the strength of a nation depended highly on the education of the citizens. In its essence, his proposition of educating people and advocating learning from the West was scientific and democratic enlightenment, which to some extent, became the theoretical basis of all factions advocating saving the country through education. In the Westernization Movement, China admitted officially for the first time that it needed to study Western science and technology, learning and borrowing voluntarily from modern Western science and technology.

The School of Combined Learning (1862) was established as the first educational institution that taught scientific material developed by European and American academics; at the Translation Institution (1868) founded by Jiangnan Manufacturing Bureau, Western science books were translated into Chinese; the first university in China, Peiyang College (Tianjin University now), was founded (1895); a group of young people including children were designated to study in America (1872), among whom was Zhan Tianyou, who was to become a well-known railway engineer. The dominant idea of the Westernization Movement was "the Chinese knowledge as the body, the Western learning for uses," put forward by Zhang Zhidong, an important figure in the rising Westernization Faction (Ding and Chen 1995, p. 255). The faction aimed at learning and applying practical Western manufacturing techniques, while maintaining and strengthening traditional Confucianism, the system of legal and cultural authority in Chinese feudal society. The Westernization Movement started from developing military industry by importing, on a large-scale, Western technologies and equipment. China entered the early stages of what could be termed "modern industrialization" through the introduction of foreign technologies, developing military industry operated by the government, and promoting commercial industry supervised by the government. Bureaucratic capital and national capital were accumulated during this period, and the industrial working class came into being, (according to statistics in 1894, there were well over 90,000 industrial workers), enlarging the social influence of modern science and technology. However, the Westernization Movement did not change the feudal characteristics of Chinese economic society. On the contrary, together with the economic invasion of Western powers and the monopolization of foreign-invested industry in China, the movement accelerated the collapse of China into a semicolonial and semifeudal society. During the Sino-Japanese War, the Chinese Beiyang Navy was completely annihilated by Japan, whose reform movement was 6 years later than the Chinese Westernization Movement. Hence, it could be claimed that the Westernization Movement failed in China.

Through the Westernization Movement, modern industry was developed to some extent in China. The success of the 1911 Revolution encouraged some Chinese people in the field of engineering to save the country with science, working hard for the prosperity of the country. They planned to found a national academic organization for engineers, so as to promote the development of engineering in modern China. Under the pressure of mass movements, China took back the right of mining from Western powers in the year 1905. National capitalist industry and commerce developed rapidly when the Western powers were occupied with fighting in the First World War. Science and production technologies were imported on a large scale from the West. The number of industrial workers increased from approximately 500,000 in the year 1911 to over two million by 1919.

Zhan Tianyou founded Chung Hwa Society of Engineers in Guangdong Province in 1912; Yan Deqing (颜德庆), Wu Jian (吴健), and others founded the Chung Hwa

Engineers Society in Shanghai; Xu Wenjiong (徐文炯) set up the Railroad Engineers Union, also in Shanghai. The three organizations reached an agreement and merged into the national Chung Hwa Institute of Engineers in Hankou in August 1913, with Zhan Tianyou elected as the first president because of his prestige. The chief aim of the institute was for engineers to communicate with each other, to study engineering, and to develop Chinese engineering and construction as a collective effort. There were 146 members when the institute was founded. In March 1918, a group of Chinese students and trainees who studied engineering in the USA negotiated Chinese Engineering Society, with Chen Ticheng (陈体诚) elected as president, and attempted to organize engineers and technicians for the further development of modern Chinese industrial technology. There were 84 members when the society was founded. Only five annual conferences were held by this society in the USA, but the participants were talented, vigorous, and well-educated young people equipped with modern knowledge of science and technology, so there was always a very lively atmosphere at the conferences, and the number of members enrolled reached over 1,000 in a couple of years. Since many members came back to the country in the following years, the annual conferences were held in China after 1935 (Shi et al. 2009). In the premodernization period, the most prominent project in China was the Beijing-Zhangjiakou Railway constructed under the direction of Zhan Tianyou.

Pillar I[1]: Zhan Tianyou and the Beijing-Zhangjiakou Railway

In early times, Chinese railways were inseparable from the famous railway engineer Zhan Tianyou, born in Nanhai County, Guangdong Province, in 1861. When he was only 12 years old, he went to study in the USA. As a student, he made up his mind to enrich his homeland through building railways. In June 1881, he graduated with the highest score from Yale University, specializing in railway engineering. He came back to China in August 1881. When he was in charge of the construction of the railway between Tanggu and Tianjin, and also Luanhe Bridge, he demonstrated his engineering talents for the first time, which were also recognized and admired by the sometimes-arrogant foreign engineers. Zhan Tianyou directed many significant projects throughout his life, with the most prominent contribution being the construction of the Beijing-Zhangjiakou Railway.

In May 1905, the Beijing-Zhangjiakou Railway Bureau and Engineering Bureau were founded, with Chen Zhaochang (陈昭常) appointed the general director and Zhan Tianyou the vice director and chief engineer. When Zhan Tianyou was promoted to general director and chief engineer, he knew well what an arduous job it was. He later wrote to his teacher Mrs. Northrop in the USA:

> If the Beijing-Zhangjiakou Project turned out to be a failure, it would not only be my misfortune, but also the misfortune of all Chinese engineers and a great loss for China. Before and even

[1] The pillars are to be understood as very important historical events in different periods of engineering development in modern China.

> after I undertook this project, many foreigners declared that Chinese engineers would never be able to handle the stonework and caves between Beijing and Zhangjiakou, but I'm sure that I could succeed.
>
> (Zhan 1989, pp. 99–100)

This is the embodiment of Chinese intellectuals' unswerving loyalty to the homeland and their sense of responsibility for the nation. On September 24th, 1909, Beijing-Zhangjiakou Railway was completed, 2 years ahead of schedule, costing only one fifth of the expense estimated by foreigners. This railroad connected Beijing and north-western China, dashing the desires of the UK and Tsarist Russia to construct the railroad. In the meantime, Chinese confidence was considerably boosted because they had built the railway themselves.

Further Developments in the Premodernization Period

The adoption of a modern education system was one of the greatest achievements of the constitutional reform and modernization. On the first day of the reform, orders were given to build Peking Imperial University and middle schools, primary schools, and industrial schools in the provinces. Orders were also given so that translation institutes should be set up, invention and creation should be encouraged, and patent right should be protected. Although the reform turned out to be a failure, with most policies not implemented, the encouragement of building schools was retained up to the year 1905 when the imperial examination system was abolished, and the various disciplines of modern science and technology were formally adopted into education. At the same time in China, the socialization process of a scientific organizational system began to take hold. A series of academic and scientific institutions were founded, such as the Chinese Geographical Society (1909), Chung Hwa Institute of Engineers (1913), Geological Survey Institute (1913), the Science Society of China (1915), and the Chung Hwa Medical Association (1915).

In the late nineteenth century, advanced scientific ideas such as the theory of biological evolution in Thomas Henry Huxley's *Evolution and Ethics* translated by Yan Fu (严复) and the economic thought in Adam Smith's *The Wealth of Nations* exerted enormous influence on educated individuals, urging the awakening of a Chinese nation. Since the twentieth century, the Mind Emancipation Movement and New Culture Movement, characterized by the slogan of science and technology first advocated in May Fourth Movement, accelerated the spread of science and social changes. Founded in 1915, the Science Society of China became the most influential scientific organization that lasted for the longest time in modern China, aiming to "unite the like-minded and conducting academic research so as to develop science in China." It encouraged the members to put emphasis on the spread of Western scientific ideas when undertaking scientific studies. Chinese scientists represented by the mathematicians Ren Hongjun (任鸿隽) and Hu Mingfu (胡明复), the geologist Yang Quan (杨诠), and the chemist Wang Xinggong (王星拱), etc., had a profound influence on Chinese when they systematically and continually introduced Western scientific knowledge, thoughts, methodology, and spirit to China. They introduced scientific concepts and modern scientific methods such as experimentation, induction, and deduction into China, which not only changed the knowledge structure of Chinese people but also greatly influenced their mode of thinking. During this period, key projects in China were the Beijing-Shenyang Railway and Beijing-Zhangjiakou Railway. Generally speaking, science and technology in this period of China were comparatively underdeveloped, staying far below the world's most advanced level, in stark contrast to the extensive scientific achievements in ancient China.

Change from Traditional Society to Modern Society (1919–1949)

The consequences of challenge and response during the previous stage continued into this period. The Westernization Movement occurred when China pursued Western-advanced armaments (material culture, culture of utensils), reflected on the reasons for China's successive failure, and studied advanced Western science and technology. The 1911 Revolution broke out when China imitated Western systems and cultures and experienced the reform movement which led to the Hundred Days Reform of 1898; the May Fourth New Culture Movement came when China pursued spiritual culture and value, shouting the slogans "Down with Confucius and Sons," and "Re-evaluate all Values." This period, as Mao Zedong (毛泽东) put it, was "the Period of New Democratic Revolution." The major challenges for China were the systematic import and assimilation of Western science and technology, as well as the invasion of Japan. Chinese intellectuals responded by launching the May Fourth New Culture Movement, during which they replaced the traditional Chinese doctrine of Confucius and Mencius with utter devotion to science and technology in pursuit of "democracy" and "science," from which came the theme of saving the country with science.

The outcome of the May Fourth Movement was "saving outweighing enlightenment." This meant that saving the country from collapse was more important than enlightening the Chinese people to Western civilization, and so the Chinese Enlightenment Movement was discontinued, and the criticism of feudal tradition was incomplete. Since 1937, the war unleashed by Japan not only destroyed the modern Chinese economy but also devastated modern Chinese science and technology in its initial stage. Almost all science-technology sectors were at a standstill up to 1949.

The annual conferences of the Chinese Institute of Engineers provide insight into the development of Chinese engineering technology during this period. In August 1931, the Chung Hwa Institute of Engineers and Chinese Engineering Society agreed to a merger and founded the Chinese Institute of Engineers at their annual conference in Nanjing, which became the headquarters of the new institute. The aim of the institute was to unite people within the engineering community, to develop Chinese engineering through shared effort, and to research and enhance engineering. With 2,169 members at its foundation, this institute was the largest of the time. In the following decade and beyond, the institute contributed significantly to the development of modern Chinese engineering and technology and the unity of Chinese engineers and technicians.

When the number of members reached over 16,000 in 1949, the institute became the largest society of science and technology in modern China with the longest history and largest number of members. Most activities organized by the institute were annual conferences, at which participants read their papers and discussed key construction issues in China. For example, the issue of engineering education in 1926, the issue of cities in 1928, the issue of industrial development in 1936, the patent issue in 1940, the issue of industrial standardization in 1941, the issue of constructing northwestern China in 1942, the issue of constructing southwestern China in 1943, and the issue of transportation in wartime in 1945. In encouraging innovations and creations, the institute awarded gold medals of engineering honor to Hou Debang (侯德榜) in 1935 for his great contribution in soda manufacturing and his book *Manufacture of Soda*, to Ling Hongxun (凌鸿勋) in 1936 for directing the construction of the hardest and most dangerous parts of Longhai Railway and Aohanlu Railway, to Mao Yisheng for designing and directing the construction of the well-known Qiantang River Bridge in the year 1941, to Sun Yueqi (孙越琦) in 1942 for prospecting the northwestern oil field, to Zhi Bingyuan (支秉渊) in 1943 for his success in developing diesel engine in China, to Zeng Yangfu (曾养甫) for directing the construction of Chengdu Airport in 1944, to Gong Jicheng (龚继成) in 1945 for directing the construction of Ledo Road and the Pipeline, to Li Chenggan (李承干) in 1946 for his contribution to ordnance industry, and to Zhu Guangcai (朱光彩) in 1947 for his success in leading people to close up the break in Huayuankou in Huanghe River (Shi et al. 2009).

Proceedings of the institute were named *Engineering*, which published over a hundred issues. Content of this magazine covered news about domestic and overseas engineering and construction, transactions and abstracts of related institutes, as well as engineering articles which were chiefly academic understanding of Chinese technical issues, representing the standard of modern Chinese engineering and technology. *Special Issue*, *Special Issue on Engineers' Day*, and *Special Issue for the Conference* were published by the institute as well. Other publications included books such as *American-Chinese Engineering Dictionary*, *A Sketch of Beijing-Zhangjiakou Railway* by Zhan Tianyou, and *Locomotive Series*, all varieties of term books, experiment reports about various building materials, reports on investigation at different places, etc. As will be described next, the key project in China in this period was the Qiantang River Bridge.

Pillar II: Mao Yisheng and Qiantang River Bridge

Qiantang River Bridge is located to the south of the West Lake in Hangzhou City, Zhejiang province, near Liuhe Pagoda. It is the first double-decked bridge for both highway and railway designed and built by Chinese, spanning the south and north of Qiantang River and connecting Shanghai-Hangzhou-Ningbo Highway and

Zhejiang-Jiangxi Railway. It took 3 years and a month to build this bridge from August 8th, 1934 to September 26th, 1937. The bridge facilitated transportation across Qiantang River and made possible the viewing of spectacular scenery together with Liuhe Pagoda to the south of the West Lake Scenic Area.

Dr. Mao Yisheng, a contemporary bridge expert, was the designer and chief director of the construction of the bridge. To accomplish his mission, Mao Yisheng resigned from his teaching position at Peiyang College, coming to Hangzhou as the chief designer and chief engineer of the Qiantang River Bridge. He succeeded in driving piles into the riverbed with the pneumatic caisson method, confounding the predictions of foreigners that "the water is deep and the current is fast, so a bridge can never be built over Qiantang River." Workable as his bridge construction plan was, it cost two million yuan at the time less than the plan proposed by an American bridge expert. Many years later, Mao Yisheng recollected, "ever since I came back to serve the country from abroad in December 1919, the most prominent job I've done during the decades was taking charge of the Qiantang River Bridge Project." Qiantang River Bridge stood as a milestone in the Chinese history of bridge construction and the cradle of Chinese bridge engineers.

Change from Traditional Society to Modern Society (1949–1978): The Period of Independent Development

In the middle of the twentieth century, through Chinese people's persistent striving, China won its independence from foreign invaders. Soon after the foundation of New China (The People's Republic of China), the Communist Party of China (CPC) and the Central People's Government gave priority to the development of science and education. The founding of the Chinese Academy of Science in 1949 marked the beginning of the independent development period of Chinese science and technology. In this period, the major challenges for China were the siege and blockade by Western countries led by the USA and the Soviet Union's withdrawal of its experts from China in July 1960, which led to a rupture in relations between the two countries. The Chinese government pursued the strategy of independence and self-reliance, advocating people to "march toward science" and "learn from all countries." The goal of development for China at the time was to "surpass England and catch up with America," realizing the "Four Modernizations." The implementation of "The First Five-Year Plan" (1953–1957) laid a foundation for the industry of New China, the emergence of the eight industry zones which included the industrial zone of coal and the industrial zone of steel, the 15-year-long "Third Front Construction," the rational distribution of industry across the whole country, and the economic take-off of China.

Zhou Enlai (周恩来) proposed the national objective of modernizing industry, agriculture, communications and transportation, and national defense at the First Plenary Session of the First National People's Congress (NPC) in September 1954. Later, Mao Zedong added the modernization of science and culture. In 1964, at the

First Plenary Session of the Third NPC, Zhou Enlai declared formally that the aim of the national development was the modernization of industry, agriculture, national defense, and science and technology. The emphasis was placed on the development of economy and science and technology.

The year 1956 was a milestone in the history of the development of modern Chinese science and technology because in January of this year, China proclaimed "marching toward science." When Japan and the USA were still hostile to New China, Zhou Enlai advocated "learning from all countries." The first long-term plan, "The Long-Term Plan of Scientific and Technological Development (1956–1967)" (i.e., The Twelve-Year Plan), was worked out to encourage the development of science and technology in China, confirming the important fields and crucial issues of scientific and technological development, such as semiconductor technology, computer technology, automation technology, radio technology, nuclear technology, and jet technology. With the joint effort of scientists, engineers, and the support of the entire nation, the general framework of scientific and technological system took shape, which promoted the emergence and development of a series of new industries and sectors of industries. After "The Long-Term Plan of Scientific and Technological Development from 1956 to 1967" was accomplished, five years ahead of schedule, the government formulated the policy of scientific and technological work. The basic task of scientific research institutions was to "make achievements and cultivate talents," and "The Plan of Scientific and Technological Development from 1963 to 1972" concentrated on the implementation of key scientific research projects and technological projects, making important breakthroughs in the fields of nuclear technology, missile technology, and space technology using China's own technical systems and effort.

With sound policies and concrete enforcement measures, China followed the guideline of "developing key areas and catching up with others" in its scientific and technological work. In extremely unfavorable conditions, China made the following surprising scientific and technological developments—in 1958, the first Chinese vacuum tube computer was developed and the first sounding rocket was launched; in 1959, the semiconductor diode and crystal triode were manufactured in China; 1964 saw the first explosion of atomic bomb in China; in 1965, a transistor computer was made and integrated circuits were developed in China; and 1967 saw the first explosion of a hydrogen bomb in China. These scientific achievements, indicating that China had caught up with the world's advanced level in certain scientific areas in a short period of time, enormously enhanced China's position in the world and exerted a widespread and profound influence on the development of science and technology in China. As Deng Xiaoping (邓小平) concluded,

> China must develop high technology by itself, so as to have a place in the world in the field of high technology. If China had neither exploded the atomic bomb or the hydrogen bomb, nor launched satellites since the 1960s, it could not become an influential great power, or be in such a leading position in the world. These embody the capability of a nation, and the prosperity of a nation, a country.
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> (Deng 1993, p. 279).

Pillar III: Li Siguang (李四光) Refuted Foreigners' Assertion of "China Oil Deficiency"

Since the Second Industrial Revolution in the second half of the nineteenth century, oil, lifeblood of industry, became one of the most important energy sources. In the early twentieth century, Western countries sent experts and scholars to prospect mineral resources in China. During the First World War, a drilling team sent by American Standard Oil Company drilled seven wells in northern Shaanxi, where they believed oil might be found, but with no success. Foreigners from other countries also looked for oil everywhere in China and left empty-handed. They drew the conclusion that China was oil poor.

With large-scale economic construction, New China encountered oil shortages. There were only a few small oil wells at the time, the annual output being 120,000 tons. So 80–90% of the oil needed by the country was imported. By the end of 1953, Mao Zedong and Zhou Enlai invited Li Siguang to Zhongnanhai, inquiring "What do you think of the saying 'China is oil-poor'? If China was really short in oil, should we produce synthesized oil?" Early in the 1930s, Li Siguang had predicted that the subsiding belts of the Neocathaysian Tectonic System in eastern China abounded with oil resources. In response to the question, he explained the geological conditions in China, making it clear that oil would be stored in the subsiding belts of the Neocathaysian Tectonic System. Mao Zedong and Zhou Enlai were convinced by his argument, so they organized large-scale explorations in the Song-Liao Plain and the North China Plain. In less than 10 years, large oil fields such as Daqing Oil Fields and North China Oil Fields were discovered. Hence, China got rid of its oil-poor reputation, which effectively proved the theory of geomechanics originated by Li Siguang. In 1964, Premier Zhou Enlai noted in the Report on the Work of the Government, "Daqing Oil Fields were discovered on the basis of the geology theory of petroleum initiated by a geologist of our own country."

For 60 years, generation after generation of excellent geologists, represented by Li Siguang, were proud of "working diligently in spite of difficulties to exploit mineral deposits, devoted to geological careers." Their exploration work made China a great power with regard to mineral resources. In 1949, the reserves of only two minerals and 300 mines were known, while today 171 minerals are found in China, with over 20,000 mines proving the extent of mineral reserves. Reserves of lead, zinc, tungsten, tin, antimony, rare earths, magnesite, gypsum, graphite, and barite rank first in the world. The total amount and reserves of mineral resources rank the top in the world, while the total amount of the mineral resources exploited ranks second. At present, 90% of the nonrenewable energy sources, over 80% of industrial raw materials, 70% of agricultural production materials, and over 30% of water used for both industry and household come from mineral resources. There are some 10,000 mine enterprises of large or middle scale and over 110,000 small-scaled ones. Over 300 mining cities sprung up in China, including the cities of Daqing, Panzhihua, Pingdingshan, Jinchang, Baiyin, and Jiayuguan.

Pillar IV: "Two Bombs and One Satellite"

"Two Bombs and One Satellite" originally referred to the atomic bomb, guided missile, and man-made satellite and later included both the atomic bomb and the hydrogen bomb. On October 16th, 1964, the first atomic bomb was successfully exploded in Luobupo, China and on June 17th, 1967, the first hydrogen bomb. The first man-made satellite was launched on April 24th, 1970. "Two Bombs and One Satellite" was perhaps the most significant technological achievement of the Chinese nation in the second half of the twentieth century. The terminology actually represents, generally speaking, nuclear technology and space technology developed by China, instead of representing any specific bombs and satellite.

After the foundation of the PRC, pressured by the force of nuclear weapons, China made *The Long-Term Plan of Scientific and Technological Development from 1956 to 1967* initiated by Zhou Enlai, Chen Yi (陈毅), Li Fuchun (李富春), and Nie Rongzhen (聂荣臻) in 1956. Mao Zedong declared in 1958 that, "We must develop man-made satellites," and "It is absolutely possible for us to make atomic bombs, hydrogen bombs and intercontinental missiles in ten years." In spite of the poor and arduous technical conditions in China at the time, many engineers and scientists dedicated their careers to the development of these technologies.

When China celebrated the 50th anniversary of its founding in 1999, the Central Committee of the CPC and the State Council awarded "Two Bombs and One Satellite" medals to 23 outstanding scientists for their contributions to the program. In his speech at the commendation meeting, Jiang Zemin (江泽民) advocated the "Two Bombs and One Satellite" spirit, which is "loving the motherland and contributing selflessly; being independent and self-reliant and striving strenuously; cooperating and progressing" (Jiang 2001, p. 166).

Change from Traditional Society to Modern Society (1949–1978): Continued

Before New China (1949) was founded, there were no more than 50,000 scientists and engineers, among whom less than 500 were engaged in scientific research in over 30 scientific research institutions throughout the country. Scientific research conducted at the time was chiefly concerned with classification of the natural conditions and characteristics of resources in China. Industrial production technology was underdeveloped, while agriculture production basically remained unchanged from several thousand years ago. Modern science and technology was almost nonexistent in every dimension of society. Since the foundation of New China, the country cultivated a group of 9.6 million scientists and engineers, among whom approximately 700,000 achieved a senior title. An integrated scientific and technological research system was established, with over 5,000 independent scientific research institutions and another 5,000 scientific research institutions affiliated to enterprises, colleges, and universities (Hong 2009, p. 285).

In general, the founding leaders of CPC, led by Mao Zedong, worked hard to explore the ways of developing socialist science and technology and education that conformed to the situation in the country. They not only developed the preliminary ideological system of socialist strategies and policies of scientific and technological development, but also succeeded in carrying out socialist education, thus, establishing a socialist education system. In the 17 years soon after the foundation of New China, science and technology and education were developed quickly and tremendously, but since the late 1950s, due to the disturbance of "left" thought, the development of science and technology and education was seriously impeded by political movements. During the "Cultural Revolution," the "left" went to its extreme, so the development of science and technology and education was severely disrupted; many scientists, engineers, and educators were persecuted, which not only damaged economic construction but also hindered scientific development. This is forever a historical tragedy (Hong 2009, p. 275).

Considering the scale, money invested, and labor consumed, the most influential projects in this period included Qinghai-Tibet Highway, Wuhan Changjiang River Bridge, Nanjing Changjiang River Bridge, Guizhou-Guangxi Railway, Chengdu-Kunming Railway, and Baoji-Chengdu Railway.

Change from Traditional Society to Modern Society (1978–2011): The Period of Reform and Opening Up

The major challenges for China in this period were the blockade of high technology by Western countries and the large gap between China and the developed and newly industrialized countries in terms of the accumulation of science and the level of technology. China was weak in innovative capacity, lacking in core technologies, and thus needed to "catch up" to other countries in this respect. To respond, China employed the strategy of "invigorating the country through science, technology, and education"—determined to construct an innovative country.

In more than 60 years since New China was founded, China has grown from a large agricultural country into a mainly industrial one. Led by two significant projects, "Two Bombs and One Satellite" and "Shenzhou VII," China made a historical breakthrough into some highly sophisticated technological areas such as manned space flight, large carrier rockets, lunar exploration, satellite, and navigation.

The most significant projects in China during this period are Qinghai-Tibet Railway, Beijing-Jiulong Railway, West-East Gas Transmission, West-East Electricity Transmission, North-South Coal Transport, Three Gorges Key Water Control Project, Xiaolangdi Key Water Control Project, South-North Water Transfer, Linhuaigang Flood Control Project, Gezhouba Key Water Control Project, Longyangxia Hydraulic Power Plant, Qinshan Nuclear Power Plant, Qinling Tunnel, Hangzhou Bay Bridge, and Beijing-Shanghai Express Railway.

Since China reformed and opened up, there have been four events in the development of engineering, technology, and the cultivation of talent. These are the foundation of the Chinese Academy of Engineering, the enforcement of the "invigorating the country through science, technology, and education" strategy, the construction of an innovative country, and "The Education and Training Program of Excellent Engineers" policy implemented by the Ministry of Education of China.

The Foundation of the Chinese Academy of Engineering

Zhang Guangdou (张光斗), Wu Zhonghua (吴仲华), Luo Peilin (罗沛霖), and Shi Changxu (师昌绪), academicians of the Chinese Academy of Science, published an article, "To Accomplish the Four Modernizations We Must Devote Great Efforts to the Development of Engineering, Science and Technology" in *Guangming Daily* on Sep. 17, 1982. According to the scientist Qian Xuesen, the concept of science and technology denoted the three equal parts of natural science, technological science, and engineering technology. On November 12th, 1993, the State Council approved "The Proposition of Founding Chinese Academy of Engineering." Set up in 1994, the Chinese Academy of Engineering represents both the acknowledgement of the achievements in Chinese engineering and the integration of the Chinese engineering circle at the highest level, inspiring and motivating the creative spirit of engineers and technicians. It plays an active role in promoting the development of engineering, increasing the standard of engineering technology, and enhancing the capability of research, design, construction, and operation. In stating the reasons for the establishment of the Chinese Academy of Engineering, Jiang Zemin stated:

> Engineers are important creators of new productivity, as well as explorers of emerging industries. It is the inevitable requests of accelerating economic construction and social development to respect the creative works of engineers, and to cultivate large numbers of engineers, scientists and technicians.
>
> (Jiang 2001, p. 226)

Implementation of "Invigorating the Country Through Science, Technology, and Education"

"Invigorating the country through science, technology, and education" is a development strategy put forward by the Central Committee of the CPC and the State Council. The strategy is in accordance with "Deng Xiaoping theory" and in line with the basic policies of the CPC. The strategy is based on scientific analysis and a summary of the trend and experience of economic, social, scientific, and technological development of the world in modern times. It takes into consideration the situation in China and estimates the significant effect of future scientific and technological development. This includes the effect of the development of high technology on comprehensive state power, social and economic structures, people's lifestyles, and modernization process. The strategy aims at accomplishing the ambitious goal of socialist modernization construction.

To "invigorate the country through science, technology, and education" is to put Deng Xiaoping's theory of "science and technology as primary productive force" into full practice, sticking to the principle of education as the foundation for change. It gives science, technology, and education the same importance as economic and social development, encouraging the enhancement of the ability to convert the nation's scientific and technological strength into bottom-line productivity. The objective is to improve the scientific, technological, and cultural quality of the entire nation, to develop the economy on the basis of scientific and technological advancement, and the improvement of laborers' quality to accelerate the growth of overall prosperity of the country. Within "The Central Committee of CPC and the State Council's Resolution of Accelerating Scientific and Technological Advancement" issued on May 6, 1995, the national implementation of "invigorating the country through science, technology, and education" strategy was proclaimed for the first time. At the Fifth Plenum of the 14th CPC Central Committee held the same year, the implementation of the strategy was adopted in the compendium for "The Ninth Five-Year Plan of National Science and Technology Development and Target until 2010" as one of the significant guiding principles of accelerating socialist modernization construction in China in the following 15 years or until the twenty-first century. At the Fourth Plenary Session of the Eighth National People's Congress, when "The Ninth Five-Year Plan of National Science and Technology Development and Target until 2010" was proclaimed, "invigorating the country through science, technology, and education" became a basic state policy of China. According to the statistics from the Ministry of Science and Technology of the PRC, the gross domestic expenditure on research and development increased from 40.45 billion yuan (0.6% of GDP) in 1996 to 89.6 billion yuan (1% of GDP) in 2000, while the total number of professionals including engineers, scientific researchers, and teachers increased from 19.92 million in 1996 to 21.65 million in 2000 (The Ministry of Science and Technology of the PRC 2001).

Pillar V: Three Gorges Key Water Control Project

Mr. Sun Zhongshan (孙中山) envisioned "The Three Gorges Project" as early as 1919 in referring to the improvement of the upper reaches of the Changjiang River in *The Constructive Scheme for the Country II Projects* (also known as *The International Development of China*). In 1932, the Construction Committee of the national government sent a hydroelectric survey team to prospect and take measurements for 2 months in the Three Gorges area, drafting building plans for weir projects in Gezhouba and Huanglingmiao. This was China's first survey and design aimed at exploring waterpower resources of the Three Gorges. In 1944, the United States Bureau of Reclamation's chief design engineer, John L. Savage, surveyed the area and drew up a dam proposal for the "Yangtze River Project." In early 1950, Changjiang

Water Resources Commission of the State Council was founded in Wuhan. Since 1955, led by the Central Committee of CPC, related departments made concerted efforts to work on planning for the Changjiang River basin, including prospecting, researching, designing, and demonstrating the “Three Gorges Project.” On Apr. 3rd, 1992, at the Fifth Plenary Session of the Seventh National People’s Congress, “The Resolution to Construct the Three Gorges Project on the Changjiang River” was approved. On Dec. 14, 1994, the construction formally started.

The Three Gorges Project is the largest hydroelectric project ever built in the world. It is located in Sandouping of Yichang, Hubei province, in the middle of Xilingxia, 38 km from Gezhouba Key Water Control Project in the lower reaches. The project includes the construction of main buildings and drainage works. With the investment of ¥ 95.46 billion, it took more than 11 years to construct the project from Dec. 14, 1994 to May 20, 2006.

The merits mainly include flood control, electric power generation, and shipping. The project benefits the environment, aquaculture, and the project of South-North Water Transfer. The major problems encountered during the construction included cultural relics and historic sites protection, ecological protection, and large-scale displacement of local people.

The drawbacks of the project include issues of national security, as it may become a target for military attacks. Also, rubbish washed from the riverbanks into the reservoir may seriously pollute the water and imperil the drinking water in lower reaches. Besides, high water level when retaining water may cause geological calamity such as earthquakes, landslides, rockfall, mudflow, and so on (Yin et al. 2007).

The Construction of an Innovative Country

On January 9th, 2006, Hu Jintao (胡锦涛), President of China, declared at the National Science and Technology Conference that the objective of scientific and technological development in China in the forthcoming 15 years was to turn China into an innovative country by 2020, making scientific and technological development an effective support to economic and social development. The decision of the Central Committee of the CPC and the State Council to increase overall innovative capacity is a significant strategic decision concerning the general situation of socialist modernization construction. The core mechanism for improving China’s indigenous innovation capacity is to further the enhancement of independent creative ability as the basis of scientific and technological development, moving forward along the road of independent innovation with Chinese characteristics and promoting the development of science and technology.

The core also lies in establishing independent creative ability as the key to industrial structure adjustments and growth pattern transformations, constructing a resource-saving and environmentally friendly society, so as to propel national economic development. To establish China as an innovative country means to strengthen independent creative ability as a national policy to be carried through in every perspective of modernization construction. This in turn will inspire a national spirit of innovation, cultivate advanced innovators, develop systems that encourage independent innovation, and promote innovation of theories, regulations, science, and technology, all toward further consolidating and developing socialism with Chinese characteristics.

Implementation of "The Education and Training Program of Excellent Engineers"

The series of national development strategies put forward by the Central Committee of the CPC and the State Council, such as moving forward along the road of new industrialization with Chinese characteristics, constructing an innovative country, and constructing a strong nation of talent, set a higher demand on Chinese engineering education. To make progress requires a large number of skilled engineers suitable and supportive of industrial development. To construct an innovative country and increase the innovative capability of Chinese engineers, scientists, and technicians demand a large number of innovative engineering talents. To enhance comprehensive national strength and meet the challenge of economic globalization demand an increasingly internationally competitive talent pool of engineers. Therefore, in implementing "The National Outline for Medium and Long-Term Educational Reform and Development," the Ministry of Education of China initiated, in June 2010, a key reform project titled, "The Education and Training Program of Excellent Engineers."

Expected to be carried out from 2010 to 2020, this project aims at gearing education to industry, to the world, and to the future, cultivating large numbers of qualified engineering talents of various types who are highly innovative and could meet the broad needs of economic and social development. Statistics in the June 24th, 2010 issue of *China Education Daily* suggest that 1,000 universities in China offer engineering programs to undergraduates now, which account for 90% of all universities qualified to award bachelor's degrees. It is also shown that the numbers of undergraduates and postgraduates majoring in higher engineering education reached 3.71 million and 470,000, respectively, while the number of engineers, scientists, and technicians reached some 14 million, which means China is now a great nation for engineering education. However, developed from a weak basis, Chinese engineering education is deficient in innovation and practicality, which has always hindered the reform and development of higher engineering education in China.

Focusing on the core issue of engineering capability, "The Education and Training Program of Excellent Engineers" will reform every aspect of the talent-cultivating mode. In educating undergraduates, universities should reinforce the capability of engineering practice, engineering design, and engineering innovation on the basis of general knowledge of science and culture. They should, on the one hand, reconstruct the curriculum system and the content of courses, advocating the research learning method, and, on the other hand, intensify the training of students' innovative capacity and cultivate interdisciplinary talents. When engineers study as trainees, companies should teach new talent advanced technologies and the corporate culture, promoting engineering practices and encouraging them to integrate their graduate projects with technical innovations and engineering development of the enterprises. In addition, they should train students in vocational techniques, professional attitudes, and ethics, while, at the same time, focus more on guiding college students' mental growth with a socialist core value system, giving them effective guidance in developing rational ideas and beliefs. "The Education and Training Program of Excellent Engineers" is characterized by (1) a profound involvement of industries and companies in fostering talent, (2) the cultivation of engineering talents in accordance with prevailing standards and industry standards, and (3) strengthening of students' engineering and innovative capabilities. There are five enforcement measures: (1) construct the new system of university-enterprise cocultivation, (2) reform talent training modes with a stress on strengthening engineering and innovative capability, (3) reform and perfect the engagement system and evaluation system for engineering educators, (4) open engineering education more widely, and (5) the educational and the industrial circles should join the effort to develop the cultivation standard of talents.

Conclusion

The process of scientific and technological development in China demonstrates how China gradually became a powerful nation in science and technology. This has been exemplified by the four phases of scientific and technological development: (1) "learning from foreigners to compete with foreigners" in the Westernization Movement, (2) "marching toward science and technology" in early years of the PRC, (3) "science and technology as primary productive force" in the initial period of the reform, and (4) "invigorating the country through science, technology, and education" from being self-reliant and hardworking to independent research, development, and innovation after importing and assimilating advanced technology from other countries. All in all, in some sixty years after the founding of the PRC, China, with its independent innovation and re-creation of technology learned from developed countries, experienced the development that took other countries several hundred years working "orient miracles." The modern Chinese engineering society accomplished great projects one after another, including the railway running across "roof of the world"—Qinghai-Tibet Plateau, the bridge spanning "Zhujiang Delta," Beijing-Jiulong Railway that runs through southern and northern China, and the Three Gorges Project that "makes a vast lake in narrow gorges."

China has been making outstanding achievements every decade. By the end of the year 2001, supported by and with the participation of academicians of both Chinese academy of Engineering and Chinese Academy of Science, China Association for Science and Technology, and the State Council, Chinese Academy of Engineering screened 25 greatest engineering and technological achievements in Twentieth-Century China (see Table 4.2.).

Table 4.2 Greatest engineering and technological achievements in the twentieth century in China

No.	Achievements
1	Two Bombs and One Satellite
2	Chinese character information processing and revolution of printing
3	Petroleum
4	Crop-yield-increasing technology
5	Prevention and control of infectious diseases
6	Electrification
7	Large river management and development
8	Railway
9	Ship engineering
10	Steel
11	Birth control
12	Telecommunication engineering
13	Geological prospecting and resource exploit
14	Technology of livestock and poultry farming, aquaculture
15	Radio and TV broadcasting
16	Computer
17	Highway
18	Mechanization—major complete-set technical equipment
19	Aeronautical engineering
20	Inorganic chemistry
21	Diagnosis and therapy of surgery
22	Rare metals and advanced materials
23	Urbanization
24	Light industry and textile technology
25	Coal mining engineering

However, in general, through its process of industrialization and modernization, China is still at the primary stage of socialism, lagging behind the most globally advanced countries in a majority of important engineering fields. After some 60 years, China has developed a large-scale national economic system, an integrated industrial system, and a scientific and technological research and development system more advanced than any other developing nation. In the 30 years since reform and opening up, China has made considerable progress in establishing a socialist market economy; building extensive relations in economy, trade, and science and technology with many countries in the world; and accumulating rich experience in internal development with advanced technologies, management, and capital imported from other countries.

By 2011, China has developed an ever-increasing group of 100 million engineers, scientists, and technicians. As Jiang Zemin once pointed out, "Innovation is the soul of a nation, the inexhaustible driving force of a country's prosperity." The Chinese engineering community should and will promote innovation in the new century, dedicated to the industrialization and modernization of China.

Acknowledgement We would like to express our gratitude to Mike Murphy, Dublin Institute of Technology, Ireland, and Erich Schienke, Pennsylvania State University in the USA, for copyediting and proofreading this chapter.

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