Construction of Chinese national S&T innovation system and latest advancements in science and technology in China

Yongxiang Lu

Chinese Academy of Sciences, 52 Sanlihe Road, 100864, Beijing, China

Chinese national S&T innovation system and the knowledge innovation programme

The evolvement of science in China from classic to modern phases traces back to the late 16th century, when Christian priests first came to China. The founding of the Central Academy of Sciences in 1928 marked the entry of China's scientific undertakings to an organic stage. Yet the establishment of a national-scale scientific system had not begun until the fifties of the 20th century when the People's Republic of China and the Chinese Academy of Sciences (CAS) were founded. As a logical development of this historical process, the Knowledge Innovation Programme (KIP) is to establish a national S&T innovation system adaptive to the era of knowledge-based economy.

In the middle and late 20th century, the concept and essential meaning of 'national innovation system' had been the subject of many discussions among the international community. Owing to the various histories and traditions of different nations, and their difference in size and development level, national innovation systems are diverse. However, their essential meaning is the same: to gain superiority in international competition in the context of economic globalization and knowledge-based economy, it is a must to keep the most active production element (i.e. science and technology) in a state that all the subsystems of the national S&T innovation system are closely related in an organic way and that this uppermost strategic resource can be effectively used, adjusted and controlled by the state.

The National S&T Innovation System of China is different from those of OECD countries in that it is not only to build up a linking mechanism adaptive to the socialist market economy, but also to upgrade the country's S&T innovation capacity rapidly and to establish a number of S&T innovation bases that are internationally competitive within a period as short as possible. In 1997, a research report entitled 'Welcoming the Era of Knowledge-based Economy with the Construction of National Innovation System' was submitted to policy-makers of the country by the CAS, as a response to the domestic and international situation of politics and economy and the trend of science and technology development. In 1998, the proposal put forward in the report was approved by Chinese President Jiang Zemin, who requested the CAS to take the lead in carrying out the pilot project for building China's own S&T innovation system. On 9 June 1998, the CAS was officially authorized by the State Council Leading Group for Science and Education to implement the KIP. It is a strategic decision by the Chinese Government in the face of economic globalization and knowledge-based era in the 21st century and an important measure for implementing the National Strategy of Rejuvenating China through Science and Education. The goal of the Pilot Project of the KIP is to build the CAS up into a national scientific research base with strong, sustained capacity of innovation in the fields where the strategic needs of the state intersect with the frontiers of science and technology, a national base for training high-quality scientists and engineers and for catalysing the development of high-tech industries, and a national bank of scientific knowledge, thoughts and talent of international reputation.

On 24 November 1998, Chinese President Jiang Zemin remarked at a meeting with scientists at the Science City, New Siberia, Russia: 'The most important strategy for meeting the challenges of the rapid development of science and technology and the springing up of knowledge-based economy is to adhere to innovation, which, I think, is the soul of a nation and an everlasting driving force behind national prosperity.' The support given by the Chinese Government to the CAS for implementing the Pilot Project of the KIP is critical to the construction of Chinese National Innovation System for the 21st century.

The CAS-initiated Pilot Project of the KIP will be implemented in three phases lasting for 13 years. The startup phase, which lasted from June 1998 to December 2000, has been completed. The Project is now in the second phase of implementation (2001–2005). In the past three years, the Project has made the following progress:

1. The identification of fields where the frontiers of science and technology intersect with the strategic goals and socio-economic needs of the state, and the readjustment of the Academy's disciplinary layout accordingly, in an effort to boost new growing points;
2. The readjustment of the Academy's organizational structure;
3. The carrying out of in-depth reform on the mechanism;
4. The selection of scientific elites to build up a new generation dedicated to S&T innovation; and
5. The fostering of innovation culture, with the improvement of science parks and infrastructure facilities.

Within the next decade, the CAS aims to develop 80 national scientific institutes with strong innovation capacity and distinct features, including 30 high-level research institutes that are internationally established and 3~5 world-level institutes, in order to make due contributions to the advance of science and technology of the world, as well as fundamental, strategic and far-reaching contributions to China's economic development, national defense and social progress in the 21st century.

The CAS takes international scientific cooperation as a prerequisite condition for promoting the development of science and technology in China, and has made it an important factor of scientific research activities. Multi-level, multiform and multi-dimensional international cooperation has been conducted with scientific institutions, universities and companies from over 70 countries and regions, as well as with international organizations, with a yearly exchange volume of tens of thousands of person-times.

International cooperation has led to the upgrading of the scientific and technological level and the innovation capacity of the CAS, the conducting of high-level research work and the improvement of efficiency in talent training. Besides, it has promoted collaboration with foreign companies and created favourable conditions for the development of export-oriented high-tech enterprises in China and the entry of their products to the international market.

Through the implementation of the KIP, the CAS will enlarge the scope and develop new forms and contents of international cooperation to facilitate the development of its scientific activities.

The development of science and technology in China in the 20th century

In the first half of the 20th century, Chinese scientists had made important achievements not only in the areas of geology, biology and palaeoanthropology, but also in the frontiers of physical and mathematical sciences.

Research efforts such as the drafting of geologic maps of China, the compiling of the Illustrated Chinese Flora (Flora Reipublicae Popularis Sinicae), the discovery of 'living fossil' metasequoia and Peking man and the rearrangement of traditional science heritages were of important value not only to China, but also to the world. The investigations on the distribution of resources in China and Chinese cultural heritages were indispensable for understanding global evolution and human history.

Examples of important results achieved by Chinese scientists in the first half of the 20th century included: the determination of Planck constant by Qisun Ye (1898–1977), the testing of the Compton scattering theory by Youxun Wu (1897–1977), the discovery of early-stage doublet generation and annihilation by Zhongyao Zhao (1902–1998), the discovery of nuclear ternary fission by Sanqiang Qian (1913–1992), the experimental work (including the discovery of Ì atom) conducted by Wenyu Zhang (1910–1992), the prediction of uranium series by Dayou Wu (1907–2000), the experimental program on neutrino proposed by Ganchang Wang (1907–1998), the theory of 'Huang's Scattering' (dynamic theory of crystal lattices) in solid study advanced by Kun Huang (1919–), the work on analytic number theory and complex analysis conducted by Luogeng Hua (1910–1985), the work on mathematical statistics and probability theory conducted by Baolu Xu (1910–1970), the pilot study in topology by Wenjun Wu, the Combined Alkali Manufacture Process invented by Debang Hou (1890–1974), the theory of 3-phase migration in impeller mechanism advanced by Zhonghua Wu (1917–1992), etc.

Since the founding of the People's Republic of China, brand-new progress has been made in the scientific undertakings of the country. Specially, the implementation of the Long-term Programme for Science Development drafted in December 1956 has led to the upgrowth of a variety of disciplines, including molecular biology, nuclear physics, high energy physics, polymer chemistry, semiconductor physics, computer and automation science and technology, ecology and environmental sciences, space science and technology, and so on. Even in the extremely difficult conditions when the country was almost completely blockaded, Chinese scientists had made important achievements, such as the total synthesis of crystalline bovine insulin with bioactivity for the first time in the world, the discovery and exploitation of the Daqing Oilfield under the guidance of the theory of continental origin of petroleum, the invention of mathematical optimization method and its widespread application in agriculture and industry sectors, and the research and development of A-bombs, missiles and satellites which were closely related to the national security of China.

The implementation of reform and opening policies and the establishment of social market mechanism in China has injected new energy to the development of science and technology. Since 1984, many efforts have been made to reform the S&T system of China, such as the founding of the National Natural Science Foundation of China (NSFC) and the implementation of the National High-tech Development Research Programme, the National Major Basic Research Programme and the Knowledge Innovation Programme initiated in 1998.

In March 1986, four Chinese scientists, i.e. Daheng Wang, Ganchang Wang (1907–1998), Jiachi Yang and Fangyun Chen, signed jointly on a statement submitted to the Central Government, entitled 'Proposal on Tracing the Developments of World Strategic High Technologies'. Two days later, top state leader Deng Xiaoping gave the instruction that immediate decisions should be made in response to the proposal. A seminar attended by over 200 experts was organized by the State Council to formulate the 'High-tech Development Programme' involving 17 subjects in 7 major fields, i.e. the National High-tech Development Research Programme.

Remarkable achievements have been made by Chinese scientists not only in applied science and technology that serve the national economy, but also in the frontiers of science, such as the machine proof and automated reasoning of geometric theorems, the cross-breeding of rice, the mapping of rice genes, the R&D of high-energy colliders, the research on high temperature superconductors, the preparation of nano-scale materials, the experimentation on the *Shenzhou* manned spaceship, the launching of rockets of the Long March series, the development of supercomputers such as the *Yinhe* and *Dawning* series, the manufacturing of 6000 m underwater robots, and the research on gene engineering medicines. Most recently, Chinese scientists have worked closely with the most eminent scientists of the world in completing the Human Genome Sequencing Programme.

The Founder Ltd. founded by Xuan Wang from Peking University was a representative of technology transfer. From 1975, as the chief person-in-charge of technology, Wang has led the work of developing the raster image processing technology of Chinese characters and graphics and, later on, the electronic publishing system. He was bold enough to skip over the second-generation photomechanical composer then popular in Japan and the third-generation CRT composer popular in Europe and USA to develop the fourth-generation laser phototypesetting system, which was then not available in the foreign markets. A high-double-density information compression technique for high resolution fonts (whose compression density is 500 : 1) and a fast font restoration method were invented to overcome the technical difficulties due to the large number of Chinese characters, the diversity of Chinese fonts for print and the high resolution requirement in precision phototypesetting. He took the lead in designing a dedicated chip for raising the font restoration rate, which reached 700 characters per second, and using control date (or parameters) to characterize the width and shape of strokes, so as to ensure the uniformity of the strokes when their font size is reduced. The invention was granted a patent in Europe and 8 patents in China. Based on the technology, the *Huaguang* and *Founder* Chinese language electronic publishing systems have been in the leading position at home and abroad; they triggered a technological revolution in Chinese language newspapering and printing in China and the world, marking the ending of the 'lead and fire' era and the beginning of a 'photon and electron' age, and realizing a thorough transformation of lead print which had lasted for hundreds of years. The technology occupied 99% of the domestic newspapering market and 90% of the books and periodicals (black and white) publishing market in China, as well as 80% of the overseas Chinese newspaper market. The Japanese and Korean-language publishing systems developed by the Founder Ltd. had also created huge economic and social benefits after entering the foreign market. Afterwards, Xuan Wang initiated and led the development of large-screen Chinese newspaper editing system (LCNES), PDL-based long distance transmission technology, colour Chinese language laser phototypesetting system, PostScript Level 2 grid image processor, news gathering and editing flow management system, etc. which were original and reached the advanced international level. These technologies were rapidly disseminated, bringing about a technological innovation of the publishing and printing industries in China to a level that bids 'farewell to newspaper and facsimile printer', 'farewell to traditional electronic color separation system' and 'farewell to paper and pens', a level that leads the world. In recent years, the technical superiority and market share of Founder publishing systems have continued to increase. Presently, the Founder Ltd. has three holding companies that are listed in the stock market, including the Founder (Holding) Inc. and Founder Digital (Holding) Inc. that are listed in the Hong Kong stock market and the Shanghai Founder Yangzhong Science Group Stock Company, Ltd. that is listed in the Shanghai stock market. Besides, the group has 17 proprietorships and joint ventures, with a total of about 6,000 employees and a total investment of 5 billion yuan. The sales volume in 2000 reached over 10 billion yuan.

In recent years, the working conditions and living standards of Chinese scientists and engineers have been much improved as more and more importance is attached to the scientific undertakings of China. Recently, the Central Committee of the Communist Party of China (CPC) and the State Council held an award ceremony in Beijing, granting the 2000 top prize of the National Sci-

ence and Technology Award to Wenjun Wu (member of the Chinese Academy of Sciences) and Longping Yuan (member of the Chinese Academy of Engineering). The fundamental work carried out by the former in algebra topology has had far-reaching influences on the development of mathematics for half a century. His success in using the computer for proving mathematical theorems and solving systems of nonlinear equations has brought about a new look to the mechanization of mathematics and opened up a new road to developing mathematics in the information age. The latter broke through the forbidden zone of the classical genetic theory by advancing a new theory on rice hybridization, achieving a historic breakthrough in rice breeding. Today, quality breeds of hybrid rice take up 50% of the total rice growing area in China, the average yield increase being 20%. Since the dissemination and growing of hybrid rice, the increased rice yield has amounted up to 350 billion kg. The economic and social benefits are quite evident.

As mankind enters the new century, the world is in a historic period of transition from the industry age to the information age. This is an era full of challenges and opportunities, an era that provides every developing country an opportunity to catch up with and surpass the developed. Heading for the third-step strategic goal, China will upgrade its science and technology to a new level. The establishment of modern enterprise system and the market economy system, as well as the enhancement of the overall power of China, has offered favorable conditions for the development of science and technology. In the innovation stage, the Chinese scientific undertakings will face three important challenges: to build the national innovation system; to upgrade the nation's S&T innovation capacity; and to seek a road of development suitable for China's actual conditions. In the process of realizing the nation's third-step strategic goal, so long as we learn from the past, we will be able to push forward the science and technology of China onto a new stage, open up the era of S&T innovation, and provide strong support for China's economic construction, social development and national security.

Latest achievements in China in science and technology

Physics and chemistry

Chinese scholar Jianwei Pan successfully conducted experimental research on cryptomorphic transmission of quantum states, achieving in experiment the transfer of unknown quantum states from one photon to another (i.e. the teletransmission of quantum states) for the first time in the world. The result has made it possible to realize in experiment the means of coded telecommunication that is completely confidential in principle, and has brought into reality the basic unit operation needed by fast quantum calculation.

A research group led by Jianguo Hou and Jinlong Yang of the University of Science and Technology of China (USTC) succeeded in obtaining the density distribution of electron clouds in C_{60} of various orientations by using low temperature scanning tunneling microscopy (STM) under the conditions of positive sample bias. This was achieved when individual C_{60} molecules were deposited on $Si(111)7 \times 7$ surface. Through computer simulation of STM images in accordance with the first principles of quantum mechanics, the molecular orientation of the absorbed fullerenes with respect to the Si substract was unambiguously determined.

The State Key Laboratory of Solid Microstructure, Nanjing University, carried out successful research on the physical process of complex coupling in dielectric superlattices for the first time internationally, which disclosed the law of interactions between superlattices and electromagnetic fields, discovered the strong coupling existing between the vibration of superlattices and electromagnetic waves, proved in both theory and experiment the optical performances of long waves (such as electromagnetic-wave absorption and polaron mode) that exist in ion crystals in such microstructure materials as ion-type phonon crystals, and illustrated the physical correspondence between superlattices and lattices.

A research group of the Dalian Institute of Chemical Physics under the Chinese Academy of Sciences developed a new method of laser spectrum with high sensitivity for measuring the section of energy transfer in carbon monoxide molecular collision, and proved the important impacts of quantum interference effects upon the energy transfer in molecular collision.

A research group led by Shuwei Xu of the Lanzhou Institute of Modern Physics, CAS, synthesized for the first time a new nuclide whose half-life period is only one second or so. This achievement was made in an experiment using the Lanzhou Heavy-ion Accelerator (LHA) and the methodology for nuclide separation advanced by the research group. Besides, the group observed for the first time the delayed proton decay of Ru-89, a nuclide whose performances had never been detected before.

Earth and environmental sciences

The Chinese South Pole Icecap Expedition succeeded in drilling the ice core lying 100 m below the surface of the Antarctic icecap whose altitude is over 3,700 m, by use of self-made drills, marking the latest development in polar exploration in China.

The Cold and Arid Regions Environmental and Engineering Institute of the Chinese Academy of Sciences

completed in 1999 the Catalogue of Glaciers in China and published 18 books in 8 volumes of the Catalogue, after careful calculation and registration of the 34 indexes of glaciers, including glacier area, length, reserves, etc. in compliance with the international standards on glacier cataloguing, by use of aerial survey and relief map. In addition, 3 books in 3 volumes on the Yaluzangbu River are being published, and a database on the catalogs of glaciers has been established, making China one of the few countries that have cataloged glaciers.

From satellite data and field surveys, Chinese scientists discovered an ozone valley in the superjacent air space above the Qinghai–Tibet Plateau in summer. It was the first time that the depletion of ozonosphere had been noticed at the low and middle latitude, following the discovery of Antarctic ozone hole in 1985. The result aroused widespread concern of the global science community. Scientists from the Chinese Academy of Meteorological Sciences and the Institute of Atmospheric Physics, Chinese Academy of Sciences concluded after further investigation that dynamic and thermodynamic effects are important causes to the afore-mentioned ozone valley.

The Chinese Government organized its first scientific expedition to the North Pole from July to September 1999. The main objective was to investigate the role of the Arctic region in global change and its impacts on the climate of China, the effects of watermass exchange in the Arctic Ocean and the northern Pacific Ocean on the variability of the northern Pacific Ocean circulation, the impacts of the ecosystem and biological resources in the Arctic Ocean and adjacent sea areas upon the development of fishery in China, and so on. China has become one of the few countries in the world capable of conducting polar expeditions.

Biological and medical sciences

The sequencing of human genome was completed on 26 June 2000, with the joint efforts of scientists from China, USA, UK, Japan, Germany, France and other countries. According to the International Cooperation Programme, Chinese scientists undertook 1% of the human genome-sequencing task, drafting 30 million base pairs in the short arms of the No. 3 chromosome. The Shanghai Institute of Biochemistry and Cell Biology, CAS, discovered and cloned a new antibacterial peptide gene in the tissue of male animal epididymis, enabling the development of new medicines both contraceptive and STD preventive.

The Institute of Developmental Biology of the CAS and Yangzhou University successfully cloned two kids using the somatic cells of transgenic goats. The Institute of Medicine and Genetics, Shanghai Children Hospital succeeded in breeding a transgenic test-tube calf carrying human serum albumin genes for the first time in the world, by using biotechnologies such as test-tube calf microinjection of foreign gene into the oosperm, and the culture *in vitro* and transplantation of embryo incorporated with foreign gene. The Institute of Zoology, CAS, in cooperation with the Fuzhou Giant Panda Research Center, cloned the embryo of giant panda in the blastospheric period by implanting panda karyons into pitted ootids of rabbits. This has provided a new approach to saving endangered animals by means of cross-species cloning.

Beijing Kaizheng Bioengineering Development Inc. carried out successful research on blood substitution taking animal hemoglobins as the groundplasm, established a technical route with self-owned intellectual property rights, and thus realized the commercialization and industrialization of the technology. In cooperation with the Northern Center of Human Genome Research, Chinese scientists successfully cloned the gene of hereditary opalescent dentine disease (HOPD), and discovered that the mutation of the gene causes progressive, neurogenic deafness.

A series of important results have been achieved in the field of paleontology in recent years. The Northwest University and the Nanjing Institute of Geology and Paleontology, CAS, discovered *myllokunmingia*, *haikouichthys* and *haikouuella* in the fauna of the Chengjiang River, which existed 530 million years ago. The discovery has not only provided evidence to the theory of Cambrian Explosion, but will also rewrite the history of the origin of vertebrates. The research on *psarolepis* and *achoania* by the Institute of Vertebrate Paleontology and Palaeoanthropology (IVPP), CAS, has provided evidence for the study on the origin of teleostean and its early-stage evolution. In the study of the origin and flight of birds, researchers of IVPP advanced the viewpoints that the differentiation of advanced theropod dinosaurs had taken place before the appearance of archaeopteryx, and that the origin of feather had nothing to do with flight and was earlier than the origin of birds. The study on *Zhangheotherium quinquecuspidens* by IVPP, the discovery of *Jeholodens Jenkinsi* by China Geological Museum, and the recently published discovery of the fossils of *Hadricodium wui* have provided important information on the early evolution of mammals.

Information science and computer technology

The 'Dawning 3000' superserver system developed by the National Center of Intelligent Computer Development of the Institute of Computing Technology, CAS, whose calculating speed is 403.2 billion times per second, has the functions of scientific engineering calcula-

tion, transaction processing and network service. It has been put into the market since the late 2000.

China NetCom Broadband High-speed Network, a demonstration project for high-speed network in China developed and run by China NetCom (Corporation Ltd.) which was jointly established by the CAS, the Administration of Radio, Film and Television, the Ministry of Railways and the Shanghai Municipal Government, began to operate in 2000. The first phase of the project covers 8,490 km in length and connects 17 major cities in the southeast of China, with a total transmission bandwidth up to 40 Gb/s. As the first commercial network adopting the IP/DWDM technology in the world, the project is, on the whole, in a leading position in the field of international telecommunication and network.

Nano-scale technology and manufacturing technology

The Research Group on Advanced Carbon Materials, led by Huiming Chen of the Institute of Metals, CAS, took the lead in carrying out experimental research on the hydrogen-storage property of one-dimension nano-scale carbon materials, and synthesized a large amount of nano-scale carbon fiber with high hydrogen storage. In collaboration with the State Key Laboratory of Rapid Setting Nonequilibrium Alloy and the Massachusetts Institute of Technology (USA), the Group has successively mass-produced nano-scale carbon tubes with high purity and an average diameter of 1.85 nm by use of hydrogen plasma electric arc process.

The research group led by Ke Lu of the Institute of Metals, CAS observed for the first time in the world the 'miraculous' performance of nano-scale metal materials – super plastic ductility in room temperature conditions.

The Research Group of Functional Interfaces led by Lei Jiang under the Research Center of Nano-scale Materials, Institute of Chemistry, CAS, developed in succession a nano-scale material with super-hydrophilic and lipophilic functional interface and that with super-hydrophobic and oleophobic functional interface in 2000. Recently, their research on the wettability of nanotube films has led to the preparation of super-amphiphilic aligned carbon nanotube films.

The group led by Jing Cheng, Tsinghua University, has successfully developed an electromagnetic biochip with independent intellectual property rights, which comprises original technologies such as the one point pass-selective electromagnetic array technology and the electrically rotating detecting technology, marking a new step forward of the international effort in using biochips for the hybrid analysis of nucleic acid, and making China one of the countries that have independent intellectual property rights in the field of biochip research and industrialization.

Shenyang Institute of Automation of the CAS has developed, with the support of the '863 Programme', a 6,000 m underwater cable-free automated robot, making China one of the few countries that have such technology and equipment. The technology has greatly enhanced the country's deep-sea exploration capability. The National University of Defense Technology (NUDT) successfully developed China's first anthropomorphic robot, which is 1.4 m in height and weighs 20 kg. It has humanoid body, neck, head, eyes, arms and legs, and certain linguistic function. It can walk freely and quickly at a frequency of two steps a second in a low-deviation, indeterminate environment. A series of breakthroughs in the key technologies such as the physical construction, control system structure, programming of coordinated movement and control methods have been made.

Space technology

As of October 2000, China has successfully launched 47 satellites of 15 categories independently, with the satellite recovery technology reaching the world leading level, developed 12 kinds of launch vehicles in the Long March series, conducted 63 launches and sending 27 foreign satellites into predetermined orbits. In the near future, China will conduct manned space flight on the basis of the success in unmanned space flight to explore the Moon and the Mars. The existing launch vehicles and launching sites of China have already met the requirements for launching moon probes, and the related space technologies and remote sensing technology have reached the level of conducting moon exploration.

On 20 November 1999, the first Chinese unmanned space capecial, *Shenzhou-I*, was launched and recovered successfully at the Jiuqun Space Launching Center, marking a new phase of development of China's space technology.

On 14 October 1999, China successfully launched the earth resource remote sensing satellite, CBERS-I, which was jointly developed by China and Brazil, into predetermined orbit. A small scientific application satellite made by Brazil was also carried into the space. It was a good example of South–South cooperation in the field of high technology.