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Historical Reflections on Building a Science and Technology Powerhouse from the Perspective of History of Science and Technology: Also on a Renewed Understanding of “Innovation is the Primary Driving Force, Talent is the Primary Resource” (Postprint)

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Abstract

Xi Jinping has emphasized that development is the primary task, talent is the primary resource, and innovation is the primary driver. This article expounds upon the profound connotations and logical extensions of innovation as the primary driver and talent as the primary resource from the historical dimension of technological development. Deeply comprehending and grasping the essential spirit of this important assertion, and drawing upon the historical experience and wisdom of technological development, is of significant importance and value for guiding the practice of scientific and technological innovation and advancing the construction of a world-leading science and technology powerhouse.

Full Text

Thoughts on Building a World Science and Technology Power from a Historical Perspective: Reconsidering “Innovation as the First Driving Force and Talent as the First Resource”

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Abstract

Xi Jinping has emphasized that development is the top priority, talent is the primary resource, and innovation is the first driving force. This paper expounds on the profound connotations and logical extensions of “innovation as the first driving force and talent as the first resource” from the historical dimension of science and technology development. A deep understanding and grasp of the essential spirit of this important assertion, drawing upon historical experience and wisdom from S&T development, holds significant meaning and value for guiding scientific and technological innovation practice and promoting the construction of a world science and technology power.

Keywords: history of science and technology, innovation, talent, construction of a science and technology power

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Introduction

In March 2018, while participating in the deliberation of the Guangdong delegation at the first session of the 13th National People’s Congress, General Secretary Xi Jinping emphasized that development is the top priority, talent is the primary resource, and innovation is the first driving force. To deeply comprehend and accurately understand this important assertion, we must grasp the dialectical relationship between development, driving forces, and sources of power. China’s economy is currently at a critical juncture of transforming its development model, optimizing economic structure, and shifting growth drivers, moving from high-speed growth to high-quality development. To achieve high-quality development, we must have high-quality scientific and technological innovation outputs; to fully leverage the strategic supporting role of innovation in development practice, we must make good use of talent as the primary resource, thereby stimulating the first driving force. From the historical dimension of S&T development and its interaction with society, the assertion that “innovation is the first driving force” enriches and develops the strategic understanding that “science and technology are the primary productive forces,” representing a high-level summary and crystallization of wisdom based on the historical evolution of building a science and technology power. Accurately grasping the profound connotations of this assertion and drawing wisdom from historical experience in S&T and social development holds important significance and value for deepening S&T innovation reform, enhancing the capacity and level of S&T innovation supply, and advancing the construction of a modern economic system and a world science and technology power.

Innovation as the First Driving Force: A Historical Perspective

Innovation is the primary driving force for improving labor productivity and optimizing economic structures. The “key move” of China’s reform and opening-up has followed the main path of introducing, digesting, absorbing, and re-innovating world S&T achievements, while continuously reforming social production relations to adapt to productive forces development, thereby propelling 40 years of rapid national development and elevating China from a low-income to a middle-income country. To advance toward higher development levels and become a world-class modern power, relying on independent innovation to continuously provide high-level and effective S&T innovation supply for economic and social development is the only path forward.

People typically understand science and technology as the primary productive force from the perspective of productive force development factors, whereas “innovation is the first driving force” must be comprehended from a systematic dynamic perspective of labor productivity improvement. “Innovation is the first driving force” encompasses not only scientific and technological innovation as a productive force but also the reform and adjustment of production relations to adapt to the development of S&T productive forces, taking into account multiple social elements including science and technology, human resources, economic structure, and even social demand.

From the formation and development of historical scientific and technological revolutions as well as industrial revolutions, scientific revolutions have laid the scientific and talent foundations for technological revolutions, which in turn drive industrial (or industrial) revolutions—meaning that S&T innovation propels industrial revolutions. Industrial revolutions promote the development of industry and commerce, agricultural progress, and socialized division of labor, facilitating the transformation and innovation of production relations to adapt to productive forces development. This forms a system of innovation centered on S&T innovation, thereby improving labor productivity, spawning new demands for higher-level products and transformations in development models, accumulating and increasing wealth for social development, evolving from poverty elimination toward universal “inclusive” goals, continuously generating new demands for a better life, and supporting and ensuring sustainable development. Furthermore, examining the experiences of S&T powers such as the United States, Japan, and Germany, we see that through S&T system reforms that continuously adapt to and promote S&T innovation, they have formed a benign interactive relationship of systematic innovation.

The industrial revolution promoted agricultural mechanization, liberating surplus agricultural labor and facilitating its transfer to cities, thereby raising the level of wealth creation per capita. From the invention of the steam plow in 1855 to the invention and use of a series of agricultural production tools such as harvesters and threshers carried and pulled by tractors—particularly the

invention and application of large tractors—agricultural mechanization was accelerated, greatly improving production efficiency. For example, after achieving agricultural mechanization around 1950, the United States, with only 4% of its population engaged in agricultural production, became the world’s largest grain exporter, whereas in China in 1990, approximately 60% of the population was still engaged in agricultural production. The formation of agricultural mechanization freed surplus labor from agriculture, enabling it to move into cities and raising both population quality and per capita wealth creation levels. S&T development and progress also provide technical support for optimizing agricultural production and improving yield and quality, playing significant roles in areas such as industrial fertilizers, seed selection, and soil structure analysis.

S&T innovation is the fundamental driving force for promoting productivity enhancement, production relation transformation, and labor productivity improvement. The industrial revolution accelerated the development of industry and commerce, promoted production division, and the energy power revolution reduced labor intensity, creating a better life. The transition from steam power to electric power provided not only the technical foundation and prerequisite for large-scale mechanized production but also significantly reduced labor intensity, changing and optimizing human production methods. While the energy revolution provided power sources for industrial development, it also transformed human transportation tools—particularly through the invention of modern vehicles such as trains, ships, automobiles, and aircraft—broadening the scope and modes of human activity and providing convenience and comfort for creating a better life. Especially based on disciplines such as aerodynamics, the invention of aircraft and rockets expanded human activity from land and sea into space, even providing realistic possibilities for exploring space science and developing space resources. The energy revolution also provided scientific and technological guarantees for improving human living environments and lifestyles, such as ensuring comfortable living conditions with heating and cooling.

The information technology revolution has profoundly influenced and transformed human civilization and lifestyles. The information revolution enabled electricity to provide technical support for long-distance, rapid information transmission and sound recording, accelerating the transmission and feedback of social information flows. The invention of wireless communications such as the telegraph and telephone made human communication faster and more convenient. The invention of television became the most influential mass communication medium of the 20th century, greatly enriching the dissemination of information and culture and advancing the development of human civilization. The invention of electronic computers and the international internet provided an interconnected “new space” for humans to acquire, transmit, and process information in production and daily life. It can be said that the first and second technological revolutions brought humanity into industrial society, while the third technological revolution, supported primarily by electronics and computer science, propelled humanity into the information society, where information became the most important resource in the knowledge economy era. Looking to

the future, based on physical and life sciences, a new round of S&T revolutions may emerge in fields such as brain cognitive science and quantum technology, driving humanity into an intelligent society and profoundly changing and influencing future human production, life, and social development.

S&T innovation is the foundation and guarantee for promoting sustainable development of human society. S&T innovation continuously improves and optimizes energy structures, steering them toward sustainable and green directions. Energy structures are evolving from fossil fuels to nuclear energy, fusion energy, and renewable energy. The power demands of large machines during the industrial revolution made coal and oil the most important energy sources, driving the development of coal and oil industries. The development of modern nuclear physics provided the scientific foundation for developing and utilizing atomic energy. In 2000, nuclear power accounted for 16% of total global electricity generation. From the perspective of energy storage resources on Earth, power generation using light nuclear fusion energy is the most abundant. Seven countries (regions)—the European Union, United States, India, Japan, South Korea, Russia, and China—are building the International Thermonuclear Experimental Reactor (ITER) in France, which is expected to achieve the development and utilization of fusion energy in the near future. Additionally, the development and utilization of renewable energy sources such as hydroelectric, wind, and ocean energy are continuously optimizing the energy structure.

S&T innovation assists in environmental pollution control and the construction of a beautiful ecological environment for humanity. Excessive exploitation of nature and industrial development have caused environmental pollution, ecological imbalance, and environmental crises. The damage humans have inflicted on the environment must be protected and restored through scientific and technological means, while developing circular economy technologies to upgrade production processes and promoting a sustainable development model that coordinates development with environment and resources. Most of the world's current S&T powers have eliminated extensive and backward production methods through advanced S&T, reducing waste and emissions in production and daily life through technological infusion, promoting the application of clean energy, and developing clean industrial production technologies, circular economy technologies, and green high technologies to create good living environments. Humanity's growing needs for a better life entail increasingly higher requirements for environmental quality and health safety, as well as growing demand for high-quality ecological products—all of which require the guarantee of science and technology.

S&T innovation safeguards human health, improves life quality, and extends individual working lives. With the development of medicine and medical technology, humanity has continuously enhanced its ability to confront disease challenges. For example, the invention and promotion of vaccines have greatly strengthened human capacity to prevent and control infectious diseases, making indelible contributions to human health. The discovery of four different blood types provided the scientific theory for blood transfusion, saving hun-

dreds of millions of lives. The development of modern anesthesiology and its techniques has greatly alleviated treatment pain for surgical patients. Organ transplantation and artificial organs extend the lives of human patients, while the invention of medical devices such as artificial blood pumps and pacemakers, along with a series of pharmaceuticals, escorts disease control, human health, and life extension, improving the course and quality of life. The mapping of the human genome has also allowed the mysteries of life to be discovered and explained through the process of S&T innovation.

Through the brief review of S&T and social development above, we can see that the interaction between science and technology and social production is the “first driving force” for realizing innovation and an inevitable requirement for promoting social civilization progress. Many technical issues that Western scientists focus on derive from the expansion of economic activities. “Until the 19th century, industry stimulated science more than science stimulated industry... these two processes have perhaps always advanced hand in hand” [1]. Through continuous technological innovation to improve production processes and techniques, productivity is enhanced, and the quantity and quality of products and social wealth are increased to meet humanity’s needs for a better life. For example, transnational maritime trade, mining, and arms production all depend on the mutual promotion of economic activities “stimulating” S&T and S&T development supporting the economy. In modern and contemporary times (especially from the late 19th to early 20th centuries), new discoveries in basic science from laboratories drove rapid breakthroughs in technology application and industrial development, such as the application of X-rays and radium therapy [3]. Revolutions in basic science such as quantum mechanics have spawned a batch of “disruptive” technological innovations, essentially creating new demands and new industries. With society’s growing demand for S&T, institutionalized S&T research and development systems have developed rapidly, including Germany’s Max Planck Society (oriented toward basic research), Helmholtz Association of National Research Centers (oriented toward big science), and Fraunhofer Society (oriented toward industrial technology), as well as U.S. national laboratories and government-led S&T programs (such as the Manhattan Project and SDI Program), all of which played crucial roles in Germany and the United States becoming world S&T and industrial powers.

Talent as the First Resource: A Historical Perspective

“Talent is the first resource” is a philosophical generalization based on the history of S&T. Today’s science and technology are increasingly interdisciplinary and integrated, and progress in basic science must be based on the support of powerful technical equipment and the cooperation of multidisciplinary technical engineering talents. Therefore, it is necessary to coordinate the relationships between strategic scientists and key engineering technical talents, scientific research teams and industrial application development teams, among others, to cultivate and form world-class scientists, stimulate the latent innovative power

of billions, and produce more research achievements that lead the world's S&T frontiers.

Outstanding universities and first-class research institutions have gathered scientists at the forefront and top tier of human knowledge and academic fields, who continuously renew human knowledge and establish and improve disciplinary systems. In the 13th century, the University of Paris in France, Oxford University in Britain, and the University of Padua in Italy began attracting scholars from around the world, including students from Rome, Poland, Spain, and other regions. The Royal Society of Britain and the Accademia dei Lincei of Italy, as the world's oldest academies, gathered a large number of scientists such as Bacon, Newton, Boyle, and Galileo [4]. Starting in the 1930s, France created national research institutions such as the National Center for Scientific Research (CNRS), the Atomic Energy Commission (CEA), and the National Space Center (CNES), producing more than ten Nobel laureates. Germany established the Imperial Physical Technical Institute and the Kaiser Wilhelm Society for the Advancement of Science (predecessor of the Max Planck Society), gathering a group of renowned scientists and engineers. The Max Planck Society had 17 Nobel laureates between 1901 and 1999, and the subsequent formation of the "Big Four" non-profit research institutions became the cornerstone of Germany's construction of a S&T power. The United States successively established national laboratories, the National Institutes of Health (NIH), and other comprehensive national research institutions. These research institutions and national laboratories attract and gather world-class S&T talent to conduct experiments or engage in academic exchanges.

Taking top scientists, especially Nobel Prize winners in science, as an example, there is a certain correlation with the formation of S&T powers. From the perspective of nationality distribution of Nobel science laureates, between 1901 and 2017, there were 600 Nobel science awards distributed across 27 countries. Among them, the United States had 279 Nobel science laureates, accounting for 46.5%, followed by the United Kingdom, Germany, France, Switzerland, Sweden, Japan, and Russia. As shown in Table 1, the number of U.S. Nobel science laureates began to increase sharply from 1921–1940, corresponding to the rise of the United States as a world S&T power. The number of German Nobel science laureates shows a jumping pattern, corresponding to the S&T prosperity of the 1920s and the S&T rise of the 1980s–1990s. Japan proposed the strategy of "establishing the country through S&T creation" in the 1990s, began emphasizing basic scientific research, and enhanced its original innovation capacity to become a S&T power, which highly aligns with the trend reflected in the number of Nobel science laureates.

A sizable talent pool has increasingly become the foundation for building a S&T power and enhancing S&T innovation capacity. With the growing interdisciplinary integration and the complementary nature of science and technology, the construction of S&T innovation talent teams is particularly important in the era of big science. According to the 2017 China Statistical Yearbook on

Science and Technology, the United States has 1.35 million R&D personnel, with Japan, Russia, and other S&T powers ranking among the top in the world in terms of R&D personnel. Additionally, among every thousand employed persons, Switzerland has 15.9 R&D personnel per thousand, Japan has 13.4, and China has 5. Most national laboratories under the U.S. Department of Energy have talent pools exceeding 2,000 people, gathering S&T talent with global influence. Germany's "Big Four" research institutions—the Max Planck Society, Fraunhofer Society, Helmholtz Association, and Leibniz Association—each have more than ten thousand scientific researchers; in 2017, the Helmholtz Association had over 30,000 scientific and technical personnel. In these research institutions, surrounding leading scientists, there are groups of key technical engineering personnel playing indispensable supporting roles.

The rise of the United States has benefited from the aggregation of global S&T talent. The United States became a world S&T power thanks to the solid talent foundation aggregated during World War II, particularly the gathering of a group of top scientists. The successful implementation of large-scale research programs represented by the "Manhattan Project" benefited greatly from this, also laying a profound foundation for the United States to lead globally in military research. During this period, the United States successfully developed electronic computers, enabling it to occupy a leading advantage in integrated circuits and electronic computer research. The U.S. talent strategy during WWII, including preferential immigration policies for intellectual refugees and the "Alsos Mission" specifically tasked with finding outstanding scientists, allowed the United States to acquire rocket technology and talent from Germany after WWII, with over a thousand scientists including Einstein and Born going to the United States. Additionally, large numbers of scientists from Italy were also introduced to the United States. The "Apollo Program" implemented by the United States mobilized 400,000 R&D personnel at its peak, making the United States unparalleled globally in aerospace and creating many major inventions that impact human society.

After WWII, the United States' open talent policy attracted a large number of S&T elites from both Eastern and Western countries, enabling the United States to remain at the center of world science after 1940. Subsequently, a national innovation system combining "big science" oriented toward national goals and "small science" oriented toward free exploration was formed. The United States has the largest number of research universities with the highest research levels in the world. Harvard University and Yale University in the United States have gathered world-class research talent; between 1901 and 1999, Harvard University had 24 Nobel science laureates, while Columbia University, Stanford University, and the California Institute of Technology each had more than ten Nobel laureates [4]. The national laboratories under various U.S. government departments are among the world's largest research systems; for example, Bell Labs in the United States has had seven Nobel laureates. International major S&T programs launched by the United States, such as the "Human Genome Project," have also gathered global talent.

China's Science and Technology Development: Achievements and Challenges

China's brilliant S&T innovation achievements are attributable to national innovation strategies and talent. In the early days of the People's Republic of China, the S&T innovation cause had to be rebuilt from scratch. By establishing a new scientific system and a natural science framework, a large number of talented individuals returned to China, becoming the backbone of our nation's S&T development. In 1956, the central government called for "marching toward science," and under the guidance of strategically oriented national will, China organized groups of scientists to tackle key problems, achieving major S&T breakthroughs such as the "Two Bombs, One Satellite" project. The convening of the National Science Conference in 1978 ushered in the "spring of science" for China. In March 1986, the joint proposal by four scientists including Wang Ganchang led to the "863" High-Tech Development Program. From implementing the "Strategy of Revitalizing the Nation through Science and Education" to proposing the construction of a national innovation system, especially since the 18th Party Congress, China has accelerated the implementation of the innovation-driven development strategy. At the "Three S&T Conferences" in 2016, General Secretary Xi Jinping proposed the goal of building a world S&T power, clarifying the objectives and implementation path for S&T innovation in the new era. China's S&T innovation has achieved brilliant accomplishments, and the scale of its S&T workforce has also become the largest in the world.

However, according to statistics from *The Path to Building a Science and Technology Power: China and the World*, looking only at major breakthrough S&T achievements from 2012–2016 [4], the United States was selected 111 times, accounting for 44.9% of the global total; China was selected three times, accounting for 1.2% globally, equivalent to only 2.7% of that of the United States. This to some extent indicates that there remains a large gap between China and world-class innovative countries, with many "bottleneck" issues. Therefore, we need to redouble our efforts, both to address weaknesses and to strive for first-class original achievements, contributing continuous momentum for high-quality development.

Recommendations for Building a World Science and Technology Power

- (1) Vigorously promote the spirit of science, strengthen innovation culture construction, and create a favorable innovation policy environment. Uphold the combination of a truth-seeking and pragmatic scientific spirit oriented toward basic science questions and a patriotic and dedicated spirit oriented toward national strategic goals. Guide S&T personnel to pursue scientific values of "sitting on a cold bench" and "spending ten years sharpening one sword," creating a cultural atmosphere that tolerates failure and encourages innovation. Also promote the spirit of master craftsmen and establish

a rigorous scientific attitude of striving for perfection. S&T innovation is a complex systematic project; corresponding S&T achievement evaluation, reward, and talent incentive policies should be established based on different innovation goals and value orientations from basic research, key technologies (including core processes), engineering integration to industrialization, so as to mobilize the enthusiasm of various innovation entities and form an innovation policy and cultural environment conducive to promoting the integration of the innovation chain.

- (2) Cultivate and gather world-class S&T innovation talent. Deng Xiaoping emphasized that being good at discovering, uniting, and utilizing talent is one of the main signs of a mature leader [5]. Xi Jinping has repeatedly stressed that to manage China's affairs well, the key lies in the Party, in people, and in talent, and that we must gather talents from around the world for our use. We must properly manage the relationship between "quality" and "quantity" in S&T innovation talent teams, and between the "tip of the pyramid" and the "base of the pyramid" in talent structure. Building a world S&T power and an innovative country depends on gathering world-class scientists and cultivating talent teams. To build a manufacturing powerhouse, we must cultivate a large number of engineering technical talents and "craftsmen." Optimize talent echelon teams, focusing on providing talent with career development platforms and supporting resources. Establish and improve talent policies and incentive mechanisms for classified evaluation based on different stages of the innovation chain, and through optimizing talent policy supply and innovation platform construction, form a highland for talent aggregation.
- (3) Consolidate the S&T foundation and strengthen basic scientific research. Basic science innovation is the source of technological innovation and industrial revolution. On the one hand, we must strengthen strategic S&T forces, accelerate the construction of globally influential comprehensive science centers, national laboratories, and major S&T infrastructure in accordance with the deployment requirements of the "S&T Innovation 2030—Major Projects," focus on building world-class scientific research institutions and universities in the era of big science, cultivate and gather first-class talent for basic scientific research, construct world-class major S&T innovation platforms, and form internationally leading major S&T achievements. On the other hand, many of China's "bottleneck" problems are not about lacking knowledge of basic scientific principles but often involve basic issues such as insufficiently detailed basic data, imprecise process controls, or even lax manufacturing precision in key materials, devices, and production processes. These basic S&T issues cannot be bypassed; it's not that they cannot be done, but that the effort has not been made! Key material devices (including core software) that play a strategic supporting role in national development are equally important national assets. "Without a solid foundation, the earth shakes and mountains tremble"—we must exert great effort to consolidate these S&T

foundations.

- (4) Strengthen the mutual promotion between S&T innovation and industrial development to provide strong S&T support for high-quality development. Engels pointed out: “Once society has a technical need, that need will push science forward more than ten universities” [1]. Without new and higher-level demands, improvements in labor productivity to a certain extent would lead to overproduction. Therefore, strengthening high-quality S&T innovation supply is also an inevitable requirement of supply-side reform. On the one hand, S&T continuously improves product quality and adds product functions; on the other hand, it drives the emergence of new product demands and new industrial economic forms (models) to meet people’s diverse pursuits of a better life. From a development trend perspective, robotics and artificial intelligence may bring about tremendous transformations in social production and consumption patterns. Examining the experiences of Japan, Germany, and France in building S&T powers, the development of productive forces needs to drive S&T innovation, such as Japan’s Meiji Restoration and the Renaissance in Germany and France forcing S&T innovation to adapt to productive forces development. Countries such as France and the United States, when facing economic slowdowns, have timely adjusted S&T policies and plans to use S&T to drive economic and social development. Enterprises must enhance their innovation capacity to connect with research achievements in original innovation and engineering innovation; institutionalized research institutions must also adhere to demand orientation, actively connect with industrial needs, identify and solve S&T problems within those needs, and promote the application of S&T achievements in the great cause of modernization.

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