Science and Technology in Modern China, 1880s-1940s

Edited by

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Toward a History of Modern Science in Republican China

Benjamin A. Elman

Abstract

Despite the recent increase in the number of teachers of the history of science and medicine, historians of "Chinese science" until recently have spent much of their time researching issues in premodern natural studies and, usually, trying to explain why modern science, technology, and medicine arrived so late in China. The "Needham Question"—Why did a divided Europe, and not imperial China, develop modern science first?—until recently remained preeminent. This question was paralleled by scholarly efforts in other fields to explain why China did not develop capitalism or democracy before Europe. We are entering a new era that explores modern science in contemporary China in more active, rather than simply receptive, terms. Increasingly, we are able to address modern science in China from a comparative point of view and include it in the story of global science. The earlier lack of studies of modern science in China was not due to the burden of historiography alone, however. Historians used the potential sources for modern Chinese science, when available, to focus on individual Chinese scientists or representative scientific institutions in the Republic of China (1911–) and the People's Republic of China (1949–), rather than exploring the larger problems of how science has been practiced in the modern context of nationalism, state-building, and socialism.

The Historiography of Modern Science in China

Most Western accounts have described how British imperial expansion during the eighteenth century collided with a Sinocentric Qing state unsympathetic to scientific knowledge. But this view should be amended. We should not read the Qianlong emperor's (r. 1736–1795) famous 1793 letter to George III gainsaying Western gadgets as the statement of a Manchu dynasty out of touch with reality. The emperor did not categorically reject Western technology. His court simply contested the originality of the astronomical instruments—a replica of the solar system, for example—that the Macartney mission brought to China. Qianlong, on the other hand, showed great interest in the model warship equipped with cannon that Macartney presented. Unaware of the industrial revolution to come in Europe, the emperor had widely employed European Jesuits as astronomers, architects, and cannon-makers, who advised him against accepting the English demands.

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Once the Qing calendar functioned properly with Jesuit help, the emperor was not inclined to think Macartney's planetarium so fabulous. Later emperors who faced irresistible English military firepower in the aftermath of the Opium War (1839–1842) were dealing with a different set of technological circumstances. Chinese had incorporated algebra and geometry and made natural studies a part of classical studies in the eighteenth century, but the continued development of science and technology in Europe required Chinese to depend on the modern sciences introduced by Protestant missionaries in the new historical conditions of the post-Napoleonic age.

In light of the important place mathematics and astronomy occupied in Qing dynasty evidential studies (*kaozheng xue* 考證學), it is remarkable how quickly—not overnight to be sure—the Chinese people adapted to the needs of science and technology, again under the umbrella of the "investigation of things and extension of knowledge" (*gewu zhizhi* 格物致知). With the introduction of the differential and integral calculus in the mid-nineteenth century, for which the Chinese could not find an ancient, native precedent, Li Shanlan (1811–1882) and other Chinese mathematicians admitted that although the "four unknowns" notation (*siyuan shu* 四元術) was perhaps superior to Jesuit algebra, the Chinese had never developed anything resembling the calculus. Moreover, after the Opium War, the most influential Chinese mathematicians no longer were devoted exclusively to the revival of ancient Chinese mathematics. They merged European and Chinese mathematics into a new synthesis.

Even after the Opium War, missionary inroads in China remained limited. Protestant missions principally funded the new translations, newspapers, and schools that introduced modern science in the 1850s. The massive Taiping conflagration from 1850 to 1864 was led by anti-Manchu and anti-gentry discontents who took advantage of a demographic catastrophe when the total population reached about 450 million. It left a swath of destruction in South China that significantly changed the tenor of things, once the peasant rebellion was quelled using new Western armaments. From the 1860s on, the impetus for science and technology shifted from the Protestants to the reforming Qing state and its new Western-oriented policies and institutions.[1]

Dr. Benjamin Hobson (1816–1873) was among the key pioneers in the late 1840s and early 1850s. After moving to Hong Kong, Hobson, an English medical missionary, pioneered a series of medical and science translations coauthored with Chinese for his premedical classes in Guangzhou. Hobson prepared the *Treatise of Natural Philosophy* (*Bowu xinbian* 博物新編, 1851), associating

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[1] Biggerstaff 1961.

science with the Chinese tradition of "broad learning about things" (*bowu* 博物). The missionary community preferred calling science "the investigation of things and extension of knowledge" in their scientific translations for the Inkstone Press (Mohai shuguan 墨海書館).[2]

Research on Western Anatomy and Traditional Chinese Medicine

Hobson also produced a series of other works to educate his students. His *Summary of Astronomy* (1849) and the *Treatise on Physiology* (1851) were also designed for his medical students. The *Treatise on Physiology* presented modern anatomy. The missionaries believed that medicine was at a low ebb in China. Yet while Hobson was translating Western medical works into classical Chinese, the heat factor tradition, which dealt with fever-inducing illnesses and had emerged in the seventeenth century, was growing increasingly prominent in South China, where the missionaries were often assigned. Regional traditions dealing with southern infectious diseases and northern cold damage disorders continued to evolve in the nineteenth century. In the process, heat factor illnesses became a new category. The mid-nineteenth century emergence of a medical tradition stressing heat factor therapies coincided with the introduction of Western medicine in the treaty ports, particularly Guangzhou, Ningbo, and Shanghai.[3]

Chinese accepted anatomy when they could assimilate it within their focus on conduits of *qi* 氣 in the body. Moreover, Song physicians had mapped acupuncture and moxibustion therapy onto the skeletal body, and the internal organs had also been drawn and modeled. Chinese medical efforts to treat southern infectious illnesses paralleled the gradual emergence of tropical medicine during the late nineteenth century when the British Empire increasingly populated the tropics with its own physicians. These networks of doctors and their medical reporting system from Africa to India and South China in turn addressed interregional infectious diseases such as malaria. Colonial physicians cumulatively sent back information about epidemics and infectious illnesses to London, the metropole of global medicine.[4]

Chinese increasingly acknowledged the need to synthesize Chinese and Western medicine. They linked cold damage disorders to the specific illness that Westerner physicians identified as typhoid fever. Germ theory was added to discussions of warm versus cold factor illnesses. Chinese physicians began to explain the wasting of the body's natural vitality in terms of tuberculosis

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[2] Wright 2000.

[3] Hanson 2001.

[4] Anderson 1996.

(= wasting disease) and gonorrhea (= depletion illness). Western public health procedures also began to be enacted in the coastal treaty ports.[5]

Unlike Ming-Qing astronomy, which was completely reworked in the seventeenth and eighteenth centuries by the introduction of Western techniques, traditional Chinese medicine did not face a serious challenge from Europe until the middle of the nineteenth century. Except for smallpox inoculations, quinine therapy for malaria, and a number of herbal medicines unknown in China, the European medicine brought by Jesuit or Protestant missionary physicians was not superior in therapeutic results until a relatively safe procedure for surgery combining anesthesia and asepsis was developed at the turn of the twentieth century.[6]

The translations Hobson prepared led some literati to question traditional Chinese medicine in the nineteenth century, however. Xu Shou (1818–1884), John Fryer's (1839–1928) collaborator, was one of the first scholars to complain that while literati had integrated Western and Chinese mathematics, they paid little attention to the strengths of Western medicine. Xu called for a similar synthesis of Western experimental procedures, linking chemistry and Chinese strengths in *materia medica*. Outside the missionary hospitals and clinics in the treaty ports, Hobson's translations were not popular due to Chinese distaste for surgery. Hobson's works introduced invasive surgery for childbirth drawn from the anatomical sciences that had evolved in Europe since the sixteenth century. Although anatomy could pinpoint childbirth dysfunctions in women in the uterus, such procedures were dangerous even by Western standards until modern surgery integrated sterilization techniques with anesthetization procedures to make local interventions safer.[7]

From Western Medicine to Modern Science in China

Hobson's work represented the first sustained introduction of the modern European sciences and medicine in the first half of the nineteenth century. His 1849 digest of modern astronomy, for instance, presented the Copernican solar system in terms of Newtonian gravitation and pointed to God as the author of the works of creation. Thereafter, Newtonian celestial mechanics based on gravitational pull was increasingly presented in Protestant accounts of modern science. A natural theology also informed Hobson's *Treatise of Natural Philosophy*, which was the first work to introduce modern Western chemistry. Along with the fifty-six elements, the textbook presented God as ultimate cre-

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[5] Rogaski 2004.

[6] Chang 1996.

[7] Wu 1998.

ator behind all the myriad changes in things. Although later changed, Hobson's chemical terminology the names of gases in Chinese and outlined the chemical makeup of the world; Hobson's scheme supplanted the four-elements theory of the Jesuits and challenged the Chinese notion of the five phases.[8]

By including sections on physics, chemistry, astronomy, geography, and zoology for his Chinese medical students, Hobson unexpectedly attracted the interest of literati unsuccessful in the civil examinations. Fryer described a group of Chinese literati investigators who earlier had met to study Jesuit works on mathematics and astronomy. They used Hobson's *Treatise* to catch up with findings since the Jesuits. This group, which included Xu Shou and Hua Hengfang (1833–1902), also carried out experiments. After fleeing the Taiping rebels in the early 1860s, they were invited by the leader of the victorious Qing armies, Zeng Guofan (1811–1872), to work in the newly established Anqing Arsenal. Hua began translation projects with Alexander Wylie (1815–1887) and Joseph Edkins (1823–1905), while Xu worked on constructing a steamboat based on Hobson's diagrams.[9]

The Role of Treaty Ports and Modern Science in Shanghai

Among treaty ports, Shanghai by 1860 was the main center of foreign trade, international business, and missionary activity. The London Missionary Society Press in Shanghai became the most influential publisher of Western learning after 1850. It published translations from a distinguished missionary community. These missionaries worked with outstanding Chinese scholars who moved to Shanghai after failing to gain a place via the imperial civil examinations. In the 1850s, Protestant journals that published in Chinese, such as the *Shanghae Serial* 六合叢談 (*Liuhe congtan*) at Inkstone Press, introduced new fields in the Western sciences. Beginning with the *Shanghae Serial*, the literati notion of investigating things (*gewu* 格物) moved from encompassing classical learning and natural studies to designating a specific domain of knowledge within the natural sciences again called "investigating things and extending knowledge" (*gezhi* 格致). Through the Protestant translation work of Wylie, Li Shanlan, and others for the *Shanghae Serial*, the investigation of things increasingly demarcated the new Western natural sciences. A scientist was now called "someone who investigated things and extended knowledge."

A talented missionary printer and translator, Alexander Wylie produced the *Shanghae Serial* monthly in 1857 and 1858, before it suddenly stopped. Wylie made some remarkable inquiries into Chinese science and mathematics with

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[8] Andrews 1994.

[9] Bennett 1967.

the help of Li Shanlan. Through this interaction, Li successfully completed the transition from the traditional craft of algebra to the modern calculus. Wylie's and Li's 1859 translation of John Herschel's (1792–1871) *The Outline of Astronomy* (1851) grew out of their early collaboration. The astronomy of the Cambridge-educated Herschel moved away from that of the late eighteenth-century Newtonians, who had stressed geometrical demonstrations over algebraic processes.

Wylie and Li stressed modern algebra as a mathematical language for the natural sciences. They related it to traditional Chinese mathematics by substituting it for procedures solving equations with a single unknown or four unknowns. Wylie emphasized that Chinese "quadrilateral algebra" (*siyuan* 四元, "four unknowns," procedures) was superior to the Jesuits' elementary algebra and acknowledged that Western scholars had not studied the two traditional methods. Nevertheless, Li and Wylie also refuted the theory that the science of algebra had originated in China.

In the 1860s, the Qing government employed many missionaries as translators to work with the Chinese in the Qing dynasty's Jiangnan Arsenal in Shanghai. Like the Jesuits, who had changed their focus from proselytizing among Chinese, the Protestants were committed to the gospel of science in China because they also thought its success in government would redound to Christianity. Many Chinese literati saw in Western learning and the modern sciences an alternative route to fame and fortune. Literati whom the Protestants had trained in the sciences began to establish links with the ruling dynasty by serving as advisors and translators after the devastations of the Taiping Rebellion. Many Chinese who had worked for Inkstone Press in Shanghai moved from the Protestant missions to the dynasty's arsenals and new schools. In this milieu, some Chinese grasped modern evolution long before the 1890s, and others became pioneering translators of Western medical works.

During this era, conservative Manchu officials, such as Woren (d. 1871), and traditionalist literati attempted to derail foreign learning in official schools such as the Beijing School of Foreign Languages. Literati who feared that Western learning would subvert state orthodoxy produced several major anti-Christian tracts in the nineteenth century. Reformers neutralized them in the 1870s, however, and they were finally routed in the aftermath of the Sino-Japanese War.

The dynasty's pursuit of Western technology began in earnest when Yung Wing (Rong Hong 1828–1912), a Cantonese who graduated from Yale University in 1854, represented Zeng Guofan in buying all-purpose machinery in Europe in 1864. In 1863, Yung had advised Zeng to launch an ironworks in Shanghai. The Nanjing Arsenal quickly produced fuses, shells, friction tubes for firing cannon, and small cannon for the Anhui Army. New machinery was added in 1867–1868, along with some British mechanists. By 1869, Nanjing was producing rockets and trying to forge larger guns.

In 1866, the Hunanese general Zuo Zongtang (1812–1885) suggested creating a modern shipyard in Fuzhou, Fujian, to build and operate Western-style warships. The regents of the Tongzhi emperor (r. 1862–1874) quickly authorized the proposal. When Zuo was sent on military campaigns to Chinese Turkestan (Xinjiang) to put down rebellions, Shen Baozhen (1820–1879) became the director general of the Fuzhou Shipyard in 1867. Depending on French know-how, Fuzhou quickly became the largest and most modern of all the Chinese military defense industries established in the 1860s and 1870s. It also had the largest gathering of foreign employees. Until the Sino-French War of 1884–1885, Fuzhou remained a major center of French interests.[10]

Subsequently, in 1866–1867, the court approved a proposal to add a Department of Mathematics and Astronomy to the Beijing School of Foreign Languages. The goal was to teach students about modern science through instruction in chemistry, physics, and mechanics. The addition of mathematics and astronomy in particular was unsuccessfully opposed by Woren while he was a Hanlin academician and imperial tutor. Woren's failure encouraged Chinese literati to accept appointments in the Beijing School. A special civil examination in mathematics, however, was successfully opposed in the 1870s, but Li's mathematics examinations at the School of Foreign Languages were influential.

Industrialization in the Jiangnan Arsenal and Fuzhou Shipyard

The Qing government established the Jiangnan Machine Manufacturing General Bureau, usually called the Jiangnan Arsenal, in Shanghai in 1865 to administer the industrial works and educational offices. At its crest, it contained four institutions: (1) the Translation Department; (2) the Foreign Language School; (3) the school for training skilled workmen; and (4) the machine shop. In addition, the Jiangnan Arsenal had thirteen branch factories. By 1892, it occupied seventy-three acres of land, with 1,974 workshops and a total of 2,982 workers. The arsenal acquired 1,037 sets of machines and produced forty-seven kinds of machinery under the watch of foreign technicians who supervised production. From 1868 to 1876, shipbuilding in the Jiangnan Arsenal was highly productive: eleven ships were built in eight years. Ten were warships. Five of these had wooden hulls; the other five, iron hulls. All parts of each ship, including the engine, were built at the arsenal. When compared to

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[10] Pong 1994.

the warships built following French models at the leading Japanese dockyard in Yokosuka in the 1870s, the higher level of shipbuilding technology at the Jiangnan Arsenal was attained earlier.[11]

The second major industrial site for shipbuilding and training in engineering and technology was the Fuzhou Shipyard. When Zuo Zongtang submitted his 1866 memorial to establish a complete shipyard at Fuzhou, he expected that after five years he could eliminate the need for foreign experts. In return for their support, neighboring provinces would receive naval protection from the Southern Fleet based at Fuzhou. Zuo and his successor Shen Baozhen relied mainly on French expertise for Fuzhou. Once the Qing established the shipyard, however, the Fujian maritime customs left the venture in a perpetual financial bind. At its peak the shipyard employed 3,000 workers. When construction was completed, the force dropped to 1,900, with 600 in the dockyard 800 in workshops, and 500 manual laborers. The shipyard had more than forty-five buildings on 118 acres set aside for administrative, educational, and production purposes.

In terms of scale, the Fuzhou Shipyard was the leading industrial venture in late Qing China. For organizational efficiency, a modern tramway with turntables at important workshops and intersections served the whole plant. Nineteen ships, with 80- to 250-horsepower engines, were planned. Of these, thirteen would be transport ships with 150-horsepower engines. Sixteen ships were finished from 1869 to 1875. Of these, ten transports with 100-horsepower engines and one corvette as a showpiece with a 250-horsepower engine were realized. After 1874, the shipyard sent graduates to Europe, especially England and France, for advanced training.[12]

Why have we undervalued such pre-1900 industrial achievements? The answer lies principally in the fact that, during the Sino-Japanese War from 1894 to 1895, the Japanese army and navy decisively defeated the armed forces of the Manchu Qing dynasty. Since then, Chinese and Japanese patriots and scholars have assumed that Meiji Japan (1868–1911) was vastly superior to Qing China in modern science and technology prior to 1894. Actually, prior to the war, many contemporary observers thought that the Qing army and navy were superior, even if only in sheer numbers. After 1895, each side rewrote their histories to validate triumphant Japan or lament the defeated Qing. For the Chinese and the Manchus, the Sino-Japanese War turned the Qing era of Self-Strengthening reforms from 1865 to 1895 into an alleged scientific and technological catastrophe. Thousands of Chinese students who studied modern

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[11] Meng 1999.

[12] Pong 1994.

science and medicine in Meiji Japan quickly assimilated the Japanese terminology for the modern sciences under the Meiji neologism for "science" as "organized fields of learning" (*kexue* 科學; Japanese, *kagaku*).[13]

The decisive Qing defeat in the Sino-Japanese War energized public criticism of the dynasty's allegedly inadequate policies. The unexpected naval disaster and the way it was presented as Japan's technological victory shocked many literati and officials. A greater respect for Western studies emerged in China. Technology alone had not been the key determinant, however. Japan, for example, could not match China's two major battleships. But Japan proved superior in naval leadership, ship maneuverability, and the availability of explosive shells.

Enhanced by the capture of twelve Chinese warships and seven torpedo boats during hostilities, the Japanese navy added significant tonnage to the Meiji fleet. Moreover, Japanese industrialization accelerated after the Qing dynasty was forced to pay a considerable indemnity to the Meiji regime. The Japanese government used the 1895 Qing indemnity of 200 million taels of silver and later Boxer indemnities as a windfall to bankroll a massive rearmament program to address the Russian expansion in northeast China. Korea and Taiwan were ceded to Japan and became productive colonies. The indemnities meant that the money could not be used to augment the Qing dynasty's reconstruction projects. Qing reparations amounted to 450 million silver taels plus interest. This sum was never fully paid, but an estimated 669 million taels were transferred from China to the foreign countries involved. The Jiangnan Arsenal and Fuzhou Shipyard never fully recovered from the indemnities that they had to pay for over two decades. Before the war the Qing government had been unable to integrate development so that innovative institutions reinforced each other, and so the added weight of Japanese and European imperialism after 1895 tipped the scales against Qing reforms initiated in 1865.

Although the late nineteenth-century naval battles that China lost are still used to demonstrate the failure of the Self-Strengthening reforms initiated after the Taiping Rebellion, the rise of the new arsenals, shipyards, technical schools, and translation bureaus should be reconsidered in light of the increased training in military technology and education in Western science available to Chinese after 1865. If we repopulate this impressive list of factories with the human lives and literati careers they contained, then we can trace more clearly the post-Taiping successors to the native mathematical astronomers of the eighteenth century. A new group of artisans, technicians, and engineers emerged between 1865 and 1895 whose expertise no longer depended on

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[13] Elman 2003.

the fields of classical learning monopolized by the customary scholar-officials. Increasingly, they were no longer subsidiary to the dynastic orthodoxy or its old-fashioned representatives.

We should not underestimate the significance of the schools and factories launched within the Jiangnan Arsenal in Shanghai and the Fuzhou Shipyard. The arsenals, machine shops, and shipyards provided the institutional venues for an education in science and engineering. They also trained the architects, engineers, and technicians who later provided the manpower for China's increasing number of public and private industries in the early twentieth century.[14]

Past accounts of China's failures in science and its dynastic losses on modern military battlefields are instructive, but their overblown rhetoric about the reasons for that failure has overshadowed acknowledgment of the more contingent conditions that placed China at the mercy of Europe and Meiji Japan beginning in the 1890s. Above I have addressed the quieter story of long-standing Chinese interests in the natural world, medicine, the arts and crafts, and commerce under the umbrella of "investigating and extending knowledge" (*gezhi*). These endeavors set the stage for the interaction with European science, technology, and medicine under the influence of Japanese *kagaku*.

The Influence of Meiji Japan on Modern Science in China

In the late nineteenth century, an increasing familiarity with Western learning exposed the Chinese to the limits of traditional categories for scientific terminology. Increasingly, the claim that Western learning derived from ancient China was unacceptable. In the revival of traditional positions after the Sino-Japanese War, which represented the third stage of the Chinese-origins argument, younger literati perceived a latent conservatism that obstructed the introduction of modern science and technology rather than facilitated it. Hence, those students who studied abroad after 1895 began to question the use of investigating things and extending knowledge (*gezhi*) as a traditional trope of learning to accommodate modern science.

Instead, to make a complete break with the Chinese past, many turned to Japanese terminology for the modern sciences. The Japanese neologism *kagaku* 科學 (pronounced *kexue* in Chinese, lit., "knowledge classified by field"), for example, was perceived as a less-loaded term for science than "investigating things," which had so many semantic links to classical learning and the

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[14] Elman 2006, chaps. 6-7.

Song Learning conventions (often called Neo-Confucianism in the twentieth century) still in place as the curriculum for the civil examinations until 1904. By 1903, state and private schools increasingly borrowed from Japanese translations to enunciate the modern classifications of the social sciences (*shehui kexue* 社會科學), natural sciences (*ziran kexue* 自然科學), and applied sciences (*yingyong kexue* 應用科學).

Before 1894, Japan had imported many European books on science from Qing China, particularly after 1720, when the shogun Yoshimune relaxed the Tokugawa prohibition of all books related to Christianity. Many had been translated during the Ming and Qing after the Japanese expelled the Jesuits for their meddling in the late sixteenth-century civil wars there. Ricci's *mappa mundi*, Chinese translations of Euclid's geometry, and Tychonic astronomy, for example, made their way to Tokugawa Japan.[15] The Japanese also avidly imported eighteenth-century Chinese terminology for Sino-Western mathematics. Physics, chemistry, and botany books, imported from Europe via the Dutch trading enclave in Nagasaki harbor in the early nineteenth century, were translated into Japanese from Dutch.[16]

In addition, the translations on science prepared under the auspices of Protestant missionaries such as Daniel Macgowen (1814–1893) and Benjamin Hobson in the treaty ports were immediately coveted by the Meiji government. Prominent translations into Chinese of works dealing with symbolic algebra, calculus, Newtonian mechanics, and modern astronomy quickly led to Japanese editions and Japanese translations of these works. Macgowen's 1851 *Philosophical Almanac* and Hobson's 1855 *Treatise of Natural Philosophy* came out in Japan in the late 1850s and early 1860s. Four other of Hobson's medical works from 1851 to 1858 came out in Japan between 1858 and 1864.[17]

In early Meiji times, many Japanese scholars still preferred Chinese scientific terms over translations derived from Dutch Learning scholars. The Chinese name for chemistry (*huaxue* 化學), for example, replaced the term *chemie* (*semi* セミ in Japanese) derived from the Dutch. Similarly, the impact of Jiangnan Arsenal publications can be seen in the choice of Chinese terminology for metallurgy (*jinshi xue* 金石學, which also meant "study of bronze and stone inscriptions") in Japanese publications. The Chinese characters were later changed in Japan and reintroduced to China using a new term for "mining" (*kuangwu xue* 礦物學).

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[15] Horiuchi 1994, 119–155. See also Jiang 2003.

[16] Kobayashi 2002.

[17] Wang Yangzong 2000.

Japan's Iwakura mission visited Shanghai in September 1873 at the end of their journey to Europe and the United States and took a tour of the Jiangnan Arsenal on September 4. They described the shipyard, foundry, school, and translation bureau there in very positive terms. The mission noted how the shipyard had been operated by British managers initially. The latter were aided by Chinese who had trained abroad. The account added that "now the entire management of the yard is in the hands of Chinese" and concluded: "This one yard would be capable of carrying out any kind of work, from ship repair to ship construction."[18]

When the diplomat Yanagihara Sakimitsu (1850–1894) visited China, he purchased many of the Chinese scientific translations. On his third visit, in 1872, for instance, he bought twelve titles on science and technology in thirty-one volumes from the Jiangnan Arsenal. These included works on chemistry, ship technology, geography, traditional mathematics, mining, and Chinese trigonometry (*gougu* 勾股). The Japanese government continued to buy arsenal books until 1877. In 1874, Yanagihara received twenty-one newly translated books from China. Despite the influence of Dutch Learning and of translations from China, and even though the Japanese began teaching modern Western science on a large scale in the 1870s, the Chinese did not borrow many scientific terms from Japan before the Sino-Japanese War.

Unlike the Chinese translations that were readily transmitted to and disseminated in Japan, Tokugawa authorities kept translations of Dutch Learning secret. While much has been made of the contributions of Dutch Learning to Japanese science during the Tokugawa period, the Yokosuka Dockyard remained dependent on French engineering advisors until the 1880s and British technical aid in the 1890s. There is no evidence that Dutch Learning per se enhanced the Yokosuka enterprise or determined the course of Meiji science and technology. Moreover, the impact of Dutch Learning, while important among samurai elites in the late eighteenth and early nineteenth centuries, was not sufficient to launch in Tokugawa Japan a technological revolution based on Newtonian mechanics and French analytical mathematics.

Indeed, the concrete advantages that Dutch Learning provided in the rise of modern, industrial science during the Tokugawa-Meiji transition remain undocumented. Japan's overwhelming triumph in the Sino-Japanese War created an environment in which most accounts since 1895 have simply assumed that Dutch Learning gave Tokugawa Japan a scientific head start over the Qing dynasty.[19]

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[18] Kunitake 2002, 352.

[19] Wang Yangzong 2000, 142. Cf. Wright 1998, 671; and Masini 1993, 91–92.

Japanese Science in China after 1895

From 1896 to 1910, Chinese translated science books that Japanese no longer worked with foreigners to translate. By 1905, the new Qing Ministry of Education was staunchly in favor of science education and textbooks based on the Japanese scientific system. Instead of the West being represented by Protestant missionaries such as William Martin (1827–1916) and John Fryer, Japan now mediated the West for Chinese literati and officials.[20] After the Sino-Japanese War, reformers were encouraged to study in Japan. Kang Youwei (1858–1927) promoted Meiji Japan scholarship in his *Annotated Bibliography of Japanese Books* (*Riben shumu zhi* 日本書目志) and in his reform memorials to the Guangxu emperor (r. 1875–1908). He recommended 339 works in medicine and 380 works in the sciences (*lixue* 理學), which now replaced as reference sources the formerly popular prize essays from the 1894 Shanghai Polytechnic essay competition. The Guangxu emperor's edict of 1898 encouraged study in Japan.[21]

As a publicist while in exile in Japan, Liang Qichao translated Japanese materials into Chinese at a fast clip. In addition to his antiquarian interests, Luo Zhenyu (1866–1940), for example, published the *Agricultural Journal* (*Nongxue bao* 農學報) from 1897 to 1906 in 315 issues. The articles were mainly drawn from Japanese sources on science and technology. Luo also compiled the *Collectanea of Agricultural Studies* (*Nongxue congshu* 農學叢書) in 88 works, with 48 based on Japanese books. Du Yaquan edited journals in 1900 and 1901 that translated science materials from Japanese journals. These were the first science journals edited solely by a Chinese. The massive translation by Fan Diji in Shanghai of a Japanese encyclopedia took several years. When it appeared in 1904, the encyclopedia contained over 100 works, with 28 in the sciences and 19 in applied science.

Post-Boxer educational reforms of 1902–1904 were also crucial in the transformation of education in favor of Japanese-style science and technology. The last bastion of modern science as Chinese science (*gezhi*) remained the civil examinations, where the Chinese-origins approach to Western learning remained obligatory. After the examination system was abolished in 1904, Japanese science texts finally became models for Chinese education at all levels of schooling. In 1886–1901, for instance, Japan officially approved eleven different texts on physics. Eight of those, which were produced after 1897, were translated for Chinese editions. In 1902–1911, twenty-two different physics texts were approved in Japan, and seven were translated into Chinese.

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[20] Wang Yangzong 2000, 139–144, and Masini 1993, 104–108.

[21] Zhao 1897. See also Wang Yangzong 2000, 144-145; and Reynolds 1993, 48, 58–61.

Similarly, in chemistry, from 1902 to 1911, seventy-one Japanese texts were translated into Chinese. Most were produced for middle schools and teachers colleges. Twelve middle school chemistry texts were produced in Japan between 1886 and 1901. Of these, six were translated into Chinese. Eighteen Japanese middle school chemistry texts were produced between 1902 and 1911. Five were translated into Chinese. Japanese scientists were also invited to lecture in China. Chinese also translated more technical physics and chemistry works from the Japanese. Iimori Teizō's (1851–1916) edited volume *Physics* (*Wuli xue* 物理學; *Butsurigaku*) was translated into Chinese at the Jiangnan Arsenal from 1900 to 1903. The translators were aided by the Japanese educator Fujita Toyohachi (1869/70–1929). Iimori's influence on Chinese physics grew out of this project.[22]

Chinese also compiled updated Sino-Japanese dictionaries such as the 1903 *New Progress toward Elegance* (*Xin Erya* 新爾雅), which modernized ancient Chinese lexicons. By 1907, when Yan Fu was in charge of the Qing Ministry of Education's committee for science textbooks, he approved the use of Japanese scientific terms. We should not underrate the historical importance of Japanese translations for the development of modern science in China. Japanese translations were much more widely available in China than those produced earlier by the Jiangnan Arsenal had been. In addition, the new Japanese science textbooks contained newer content than the 1880s arsenal and missionary translations, which were already outdated by European standards in the 1890s. The introduction of post-1900 science via Japan, which included new developments in chemistry and physics, went well beyond what Fryer et al. had provided to the emerging Chinese scientific community.[23]

Chinese presses also published in greater numbers the translations of Japanese texts, which were easier to read because only Chinese compiled them. Moreover, the quality of the translations from works by Japanese scientists was better than that of the earlier science primers since Chinese translators themselves could understand the Japanese originals. In addition, the Japanese texts were available to a new and wider audience of students in the new public schools and teachers colleges that the Qing government established after 1905 as part of its education reforms. The Imperial University in Beijing also invited Japanese professors to join its faculty.[24]

Finally, to make the new translations more easily understood than standard classical translations, Chinese translators helped produce a new literary form

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[22] Wang Yangzong 2000, 146–147. See also Cong 2007.

[23] Masini 1993, 145–151.

[24] Weston 2004, 50–52.

for presentation of the sciences, which contributed to the rise of the vernacular for modern Chinese scholarly and public discourse. Among urbanites, especially in Beijing and Shanghai, the first decade of the twentieth century provided the basic education in modern science via Japanese textbooks for the generation that matured during the New Culture Movement of 1915 and the May Fourth era after 1919.[25]

The Delayed Emergence of Physics as a Technical Field in China

When we compare the development of modern physics in Meiji Japan and Qing China, we find that scholars in both countries had started to master Western studies in the early and mid-nineteenth century. The Translation Department at the Jiangnan Arsenal had produced Chinese books on physics beginning in the 1850s in China, and the Dutch Translation Bureau in Tokugawa Japan had provided such works in Japanese beginning in 1811. Although the introduction of Dutch Learning in the seventeenth and eighteenth centuries enabled an earlier start in Japan, the materials on physics in the Protestant translations produced in China after 1850—quickly transmitted to Japan—made those earlier studies out of date. Moreover, the Primer Series produced in the 1870s and early 1880s in China remained superior overall to its Meiji counterparts until the 1890s.[26]

Despite the range of science translations in Qing China through the 1880s, physics textbooks were not available in China until they were first published in Japan. This lack had much to do with the way the Protestant missionaries such as Martin and Fryer had introduced the physical sciences to literati audiences after 1860. Rather than a unified field of physics—or natural philosophy, as it was often called by Euro-American specialists until the 1860s—missionary translators first introduced the disaggregated branches of physics. Accordingly, mechanics (*lixue* 力學 or *zhongxue* 重學), optics (*guangxue* 光學), acoustics (*shengxue* 聲學), electricity (*dianxue* 電學), and thermodynamics (*rexue* 熱學) were presented as independent fields in China. By presenting the subfields of physics independently, the translators made it difficult for Chinese later to appreciate the unity of physics. Moreover, introducing the branches first made it more complicated later to reach a consensus on a more general term for physics.

Often physics was equated with investigating things (*gewu*). Others preferred calling physics "investigating things and extending knowledge" (*gezhi*), which frequently overlapped vaguely with the general term for science and

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[25] Wang Yangzong 2000, 147–150.

[26] Wang Bing 1994.

created substantial misunderstanding. Edkins's 1886 *Science Primers* associated "investigating the materiality of things" (*gezhi zhi xue* 格致之學) with physics. In 1895, the school of physics in the Beijing Foreign Language School changed its name from the Hall for Investigating Things (Gewu guan 格物館) to the Hall for Investigating and Extending Knowledge (Gezhi guan 格致館). Unlike the Japanese, who developed independent translation techniques, the Chinese remained dependent on their Protestant informants into the 1890s. This dependency placed severe limits on what the Chinese alone could translate. Overall, the Western translations prepared by Macgowen, Hobson, and Martin in China dealt with physics in very general, textbook terms and never produced useful handbooks.[27]

The Qing state also was slower in reforming its educational system. Meiji Japan's new educational system was established in 1868; Qing education reforms were not comparable until 1902. A Japanese Ministry of Education (Mombusho 文部省) was created in 1871; its Qing counterpart was not established until 1905. Similarly, Tokyo University was founded as Japan's key modern teaching institution in 1877; the Imperial University of Beijing did not exist until 1898. Courses in physics had already started in 1875 in Japan, when the Tokyo school that evolved into Tokyo University shifted from foreign-language lectures by Europeans to lectures in Japanese by returned students who had studied physics abroad. The first Japanese students trained in physics in Japan graduated in 1883.

Chinese science faculties were not established at the Imperial University of Beijing until 1910, but even then only classes in chemistry and geology were taught. Physics was added in 1912. Of 387 students recruited in the sciences, only 54 received diplomas in 1913. Beijing first recruited Japanese science teachers to the university in 1902, but they left in 1908–1909 after their six-year contracts expired. From 1898 to 1911, only 200 students were trained in the sciences at the Imperial University, and the initial absence of faculties of mathematics and physics remained a serious problem in training scientists. The science curriculum was formalized in terms of requirements at the high school level beginning in 1911. In Japan, there were few students of physics when compared with the more popular fields of law and medicine. Between 1882 and 1912, however, Tokyo University graduated 186 in physics.[28]

Japan's educational system had a head start in editing and translating physics textbooks. China, by comparison, lacked textbook materials to teach physics at all levels of the educational system. Similar delays occurred in other

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[27] Smith 1978; and Amelung 2004.

[28] Bastid 1988.

technical fields such as chemistry and geology. By 1873, Japanese taught physics in the new Meiji schools, and by 1877, Tokyo University had a physics program. By comparison, the Beijing School of Foreign Languages asked only occasional physics questions on examinations from 1868, which were based on Martin's elementary *Natural Philosophy*. The subfields of physics were taught separately as mechanics, hydraulics, acoustics, pneumatics, heat, optics, and electricity. In addition, the military and arsenal schools also taught some physics, especially its subfields.

Meiji educators produced physics textbooks in the 1870s, but none were available in China until the 1890s. Although Japanese relied on Protestant translations from China initially, the Ministry of Education ordered Katayama Junkichi (1837–1887) to compile an official physics textbook when physics (*butsuri* 物理, *wuli*) became a specialized discipline. Katayama's textbook was added to the Japanese curriculum in 1876 and republished many times. Moreover, Japan invited Western scientists to Japan. K. W. Gratama (1831–1888) began to serve in the Chemistry Bureau in 1869. He was succeeded by H. Ritter (d. 1874). Later, Iimori Teizō completed his edition of *Physics* by consulting the works on physics published by the German J. Müller.

In the late 1890s, the Qing recognized the need to translate physics textbooks. As a result of the 1898 reforms, the government decided to copy the Meiji model for education and create a public school system for science education rather than simply rely on schooling in the arsenals, shipyards, and factories. Full implementation of this program was not feasible until the civil examination system was scrapped, and the new school system replaced it in 1904–1905. The Sino-Japanese War had taught the Qing government that relying on arsenals to modernize was insufficient.[29]

Because there were few science textbooks in China and none that dealt chiefly with physics, Chinese immediately translated Japanese texts such as Iimori's *Physics*. In the early twentieth century, direct Chinese translations of the best physics texts by the most famous Japanese physicists were the most efficient means to prepare textbooks for the new Qing school system. This policy also guaranteed that Chinese would no longer rely on Western informants for specialized translations in important fields such as physics. But China's dependence on Japan was reconsidered after 1915, when Japan's policies toward the Republic of China became increasingly predatory.

Although high-level education in physics began at the Beijing Imperial University in 1912, the best-trained physicists studied in the United States and Japan: Li Fuji (b. 1885) studied in the United States; He Yujie (1882–1939), Xia

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[29] Wang Bing 1994. Cf. Reynolds 1993, 65–110, 131–150.

Yuanli (1884–1944), Li Yuebang (1884–1940?), and Hu Gangfu (1892–1966) studied in Japan. When the Imperial University was reorganized as Beijing University in 1912, it had formal divisions between the humanities and the sciences, with the latter including the fields of mathematics, chemistry, and physics. An independent physics department was not created until 1917, however. The greater availability of physics texts in the school system after 1905, however, did provide for wider knowledge of the field in China than had been the case before 1900.[30]

Japan also had a lead over China in physics research, the unification of technical terminology, and research associations by 1900. For instance, Japanese scholars started publishing in physics in the 1880s. Over two hundred articles in the various subfields of physics had appeared by the end of the Meiji era in 1912. Moreover, several Japanese physicists had emerged who were approaching Western levels of expertise in physics. Translators chose the official Meiji designation for the term "physics," *wuli xue* 物理學, in 1872. Terminology in Japanese physics achieved a final unification with the 1888 publication of an official list of technical terms with foreign counterparts. The committee for systematizing the translation of terms for physics, which was formed in 1885, was led by three of the first Japanese graduates in physics from Tokyo University. Scholars unified terms for 1,700 items from English, French, and German, which they then translated into Japanese and published. Chinese started using the Japanese term for "physics" in 1900, when a Japanese book by that name was published in China. Before, the term had usually referred to the principles of things as part of the traditional fields of natural studies.[31]

Academics created the first mathematics society in Tokyo in 1877, with fifty-five members. In 1884, ten of its seventy-five members specialized in physics. When the Tokyo Mathematics-Physics Society was formed in 1884, it had eighty-two members, twenty-five of whom were physicists. The latter changed its name in 1919 to the Japan Mathematics-Physics Society, which survived as an organization until it separated into two parts in 1948. Smaller specialized groups in physics were also formed in Japan in the 1880s. China was also later than Japan in training physicists and organizing associations. The Chinese had to study physics abroad, and the research institutes for physics at the Academia Sinica, the Beijing Institute, and the Qinghua Institute were not formed until 1928–1929. Although Chinese words for physics terms were unified in 1905, they were not finalized until the 1920s. Moreover, the Chinese Science Society and its journal were not founded until 1915, and that took place abroad in the

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[30] Wang Bing 1994.

[31] Wang Bing 1999.

United States at Cornell University. Physicists did not form the Chinese Physics Society until 1932.[32]

The belief that Western science represented a universal application of objective methods and knowledge was increasingly articulated in the journals associated with the New Culture Movement after 1915. The journal *Science* (*Kexue* 科學), which the newly founded Science Society of China created in 1914, assumed that an educational system based on modern science was the panacea for all China's ills because of its universal knowledge system. Meiji Japan served as the model for that panacea until 1915, when Japanese imperialism, like its European predecessor, forced Chinese officials, warlords, and intellectuals to reconsider the benefits of copying Japan.[33]

Toward Republican Science

Despite the late Qing curriculum changes described above, which had prioritized science and engineering in the new public schools since 1902 and in private universities such as Qinghua (Tsing Hua 清華), many Chinese university and overseas students were by 1910 increasingly radical in their political and cultural views, which carried over to their convictions about science. Traditional natural studies became part of the failed history of traditional China to become modern, and this view now asserted that the Chinese had never produced any science. How premodern Chinese had demarcated the natural and the anomalous vanished when both modernists and socialists in China accepted the West as the universal starting place of all science.[34]

After 1911, many radicals such as Ren Hongjun linked the necessity for Chinese political revolution to the claim that a scientific revolution was also mandatory. Those Chinese who thought a revolution in knowledge required Western learning not only challenged classical learning, or what they now called Confucianism (Kongjiao 孔教), but also unstitched the patterns of traditional Chinese natural studies and medicine long accepted as components of imperial orthodoxy.[35]

As Chinese elites turned to Western studies and modern science, fewer remained to continue the traditions of classical learning (Han Learning) or Song Learning moral philosophy (Neo-Confucianism) that had been the basis for imperial orthodoxy and literati status before 1900. Those who still focused on traditional learning, such as Gu Jiegang (1893–1980) in Beijing and others elsewhere, often did so by reconceptualizing ancient learning in light of

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[32] Wang Bing 1994.

[33] Sheng 1995, 11–12.

[34] Chen Yuanhui et al. 1991, 608–650. Cf. Geertz 1975.

[35] See Elman 1997.

"doubting antiquity" and applying new, objective procedures for historiography that they derived from the sciences. Thereafter, the traditional Chinese sciences, classical studies, and Confucianism survived as vestigial native learning in the public schools established by the Ministry of Education after 1905. They have endured as contested scholarly fields taught in the vernacular in universities since 1911.[36]

The Great War from 1914 to 1919 acted as a profound intellectual boundary between those modernists who still saw in science a universal model for the future and the "New Confucian" (Xinru 新儒) traditionalists, such as Zhang Junmai (Carson Chang 1886–1969), who showed renewed sympathy for distinctly Chinese moral teachings after the devastation visited on Europe. The former reformer and now scholar-publicist Liang Qichao, who was then in Europe leading an unofficial group of Chinese observers at the 1919 Paris Peace Conference, visited a number of European capitals. The group witnessed the war's deadly technological impact on Europe. They also met with leading European intellectuals, such as the German philosopher and Zhang Junmai's teacher Rudolf Christoph Eucken (1846–1926) and the French philosopher Henri Bergson (1859–1941), to discuss the moral lessons of the war.[37]

In his influential *Condensed Record of Travel Impressions while in Europe* (*Ouyou xinying lu jielu* 歐遊心影錄節錄), Liang Qichao related how the Europeans they met regarded the First World War as a sign of the bankruptcy of the West and the end of the "dream of the omnipotence of modern science." Liang found that Europeans now sympathized with what they considered the more spiritual and peaceful "Eastern civilization" and bemoaned the legacy in Europe of an untrammeled material and scientific social order that had fueled the world war. Liang's account of the spiritual decadence in postwar Europe indicted the materialism and the mechanistic assumptions underlying modern science and technology. A turning point had been reached, and the dark side of "Mr. Science" had been exposed. Behind it lay the colossal ruins produced by Western materialism.[38]

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36 Luo 2000; and Weston 2004, 83.

37 Ding 1972, vol. 2, 551–574. For African and Indian critiques, see Adas 2004.

38 Liang 1972, vol. 7, 10–12. See also Chow 1960, 327–329; and Grieder 1970, 129–135.

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