Science History, 1600-1900

Benjamin A. Elman

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.[1] The "Needham Question"—Why did a divided Europe, 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 did.[2]

We are entering a new era that is exploring 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 (1911–49) 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 need to use all available sources to illuminate the broader practice of science in its full modern context is obvious, but the political limits placed on sensitive topics, such as modern physics, remain in place in contemporary China. We certainly need accounts for socialist science—in China and elsewhere in Asia and Eastern Europe—that match our evaluations of capitalist science.[3]

Accounts of Early Modern Science in Late Imperial China, 1600-1750

Classical scholars in Qing China (1644–1911) reappropriated the mathematical classics and early astronomy in the millennial quest for ancient wisdom. After 1750 the Qing court during the Qianlong era (1736–95) was fortuitously buffered from contemporary European wars and the revolutionary changes then preoccupying Great Britain and France. In this geopolitical vacuum, Qing literati sought to compare what they knew of European learning, brought principally by the Jesuits, with native learning. Although the priority was on the latter, the restoration of ancient learning allowed Manchus and Chinese to bring under control early modern (1600–1800) European contributions in mathematics and astronomy.[4]

Early scholarship has focused on how the Jesuits in China devised a unique accommodation approach to gain the trust of the Qing court and its social elites. Matteo Ricci (1552–1610) and his immediate followers prioritized natural studies and mathematical astronomy during the late Ming

(1368–1644) and early Qing because they recognized that Chinese literati and Ming and Qing emperors were interested in such fields. Such literati interests in natural studies and "Western learning" continued in the eighteenth century despite the impact of the Rites Controversy. Rhetorical claims about Chinese disinterest in European science are being replaced with new scholarship that shows how prominently Christianity and science influenced Chinese literati before the nineteenth century. Literati interests in European science were cut short not by Chinese disinterest but instead by the failure of the Jesuit mission to act as a reliable conduit of scientific and mathematical knowledge during and after the Kangxi reign (1662–1722).[5]

Moreover, the Jesuits did not transmit "modern science" to China. The Chinese "lack of knowledge" about eighteenth-century scientific developments in Europe, notably Newtonian mechanics and continental calculus, represented a failure of scientific transmission that can be tied directly to the demise of the Jesuits and their schools in Europe during the eighteenth century, which vicariously affected Chinese information about new trends there. The Jesuits, for example, finally introduced an accurate account of Copernican cosmology in China only after the Church's ban on Copernican astronomy ended in 1757. Anti-Jesuit polemics generated in Europe, however, led to suppression of the order, before the Pope dissolved the order worldwide in 1773. China's "window on Europe" was shattered by forces internal to Europe.[6]

Summary of Recent Scholarship on Jesuit Mathematics in Peking

When the French Jesuits arrived in China after 1689, they introduced contemporary French science. The French mission hoped that the Kangxi emperor would establish his own academy of science, which would emulate the Academy of Sciences in Paris. The Kangxi emperor recognized the need to continue to employ French Jesuits on the calendar despite his dissatisfaction with Rome's papal policies toward China after the Rites Controversy. The Kangxi emperor also molded his own court's Academy of Mathematics (Suanxue guan) on the model of the Parisian Academy of Sciences, but it was strategically named after the Tang dynasty (618–907) school of mathematics. The academy was established in 1713 for calendrical work, but only Qing literati and bannermen were appointed. This post–Rites Controversy policy ensured that the Jesuits would not be unduly influential in court mathematics.[7]

The Kangxi court sought to escape the dynasty's reliance on the Jesuits in calendrical matters. After the *Sources of Musical Harmonics and Mathematical Astronomy* (*Lüli yuanyuan*) was printed early in the Yongzheng reign (1723–35), no other European mathematical works were introduced into China until after the Opium War (1839–42). Notably missing in China was the European discovery of the more dynamic differential and integral calculus by both Leibniz and Newton, which had exceeded the static limits of Greek geometry and Islamic algebra. Moreover, the version of Euclid's *Elements of Geometry* remained the official version until 1865.[8]

The early Qing calendars produced by the Jesuits were based exclusively on European models, but the new system cobbled together fused European with "Chinese methods." Qing specialists had no domestic incentive to go beyond the immediate needs of the Qing calendar, now successfully reformed. Nor were they intellectually pressed by the Jesuits to do so. By 1725 the latter were themselves no longer on the cutting edge of the early modern sciences, and their mathematics went no further than simple algebra, trigonometry, and logarithms, which had been domesticated by a small group of late Ming and early Qing specialists. In the eighteenth century, a larger community of Qing classical scholars associated with evidential studies (*kaozheng xue*) would restore traditional Chinese mathematics to a level of classical prestige.[9]

When compared to eighteenth-century developments in Europe, however, the fate of the Qing dynasty Academy of Mathematics is instructive. In France the Paris Academy of Sciences became a building block for an increase in science professionals and the institutions that supported them. The establishment of professional standards for scientific disciplines by the late eighteenth century was accompanied by the expansion of European universities and research institutes where professionalized science slowly incubated in institutions of higher learning and specialized laboratories eventually replaced gentlemanly academies. Not until the late nineteenth century would such developments commence in China.[10]

Summary of Research on the Qing Revival of Classical Chinese Medical Texts

During the Ming and Qing, the medical classics provided scholars and physicians with a set of general assumptions about the application of *qi*, yin-yang, the five phases, and the system of circulation tracts (*jingluo*) to understand the human body and its susceptibility to illness, which was defined as a loss of harmony in the body's operations. Since antiquity physicians had thought of the internal flow of *qi* through a series of main and branch conduits as the body's vital currents. For Qing literati-physicians, textual mastery of the medical classics and their commentaries was required to recover ancient principles and practice. The formation of evidential scholarship and the return to antiquity in medicine reinforced each other.[11]

The oldest and most important medical classic was the *Inner Canon of the Yellow Emperor* (*Huangdi neijing*黃帝內經), which was completed in the first century BCE. When set in its orthodox form during the Northern Song (960–1126), it focused on anatomy, physiology, and hygiene in the part called the *Basic Questions* (*Suwen* 素問), while presenting a basic understanding of acupuncture and moxibustion in the *Divine Pivot* (*Lingshu*靈樞). Treatments using drugs were rare, and the focus was on preventative medicine. Later the *Treatise on Cold Damage Disorders* 傷寒論 by Zhang Ji張機 (仲景, 150–219) applied the *Inner Canon* to drug therapy. Zhang wrote his book in response to contemporary epidemics. During the Northern Song, the latter became the guiding work to deal with infectious diseases brought by the winds. These were considered the cold damage disorders that were responsible for the increase in southern epidemics.[12]

When Ming-Qing scholar-physicians reviewed the texts, however, they contended that earlier scholars had not based their works on the authentic version of the *Treatise on Cold Damage Disorders*, which was lost. The diseases of the south, with their richer variety of climates, infection, and infestation, led to questioning the government's formularies based on the Song medical orthodoxy. They also historicized the concept of illness, which they saw as evidence of long-term changes in diseases brought by the winds. The heat factor approach to the treatment of the epidemic diseases of South China became more accepted during the late Ming. Due to high mortality rates of up to 70 percent in late Ming epidemics in the Yangzi Delta, physicians demonstrated that important parts of the medical classics had been improperly adapted and thus no longer represented the ancient diagnostic and therapeutic procedures advocated in the original *Treatise on Cold Damage Disorders.*[13]

Qing scholar-physicians sought to reverse the adulteration of ancient medical practice. Their appeal to the ancient wisdom in the authentic medical classics added to the growing eighteenth-century denunciations of the medical orthodoxy. Moreover, Ming physicians increasingly referred to case histories 醫案, although they were not new, instead of the medical classics to advertise their therapeutic successes and explain them to students and amateurs. Qing debates between antiquarians and modernists concerning early medicine paralleled those between Han Learning and Song Learning classical scholars. Like Han Learning scholars, Qing scholar-physicians began their studies with Han dynasty medical texts and the earliest classical interpretations, because the latter were closer in time to the composition of the classics and thereby more likely to reveal their authentic meaning. They rejected Song dynasty sources because of their questionable authority and the greater separation of the Song dynasty from antiquity.[14]

Qing medical scholars demonstrated that later interpreters had misread Tang and Song medical works. The tense interplay between an admired antiquity and a discredited Song medical orthodoxy suggests that medical studies in late imperial China were an adaptation of classical antiquity. Qing scholar-physicians thought their rediscoveries would improve contemporary medical therapies. The editors of the Qianlong Imperial Library took note of these contending medical traditions and described them using the traditional designations of schools as lineages of transmitted learning. Indeed, in 1739 the Qianlong emperor had already authorized a compilation of annotations of Zhang Ji's *Treatise* in southern medical editions. It became the standard textbook for students in the Palace Medical Service. In the midst of these eighteenth-century controversies, however, the heat factor tradition grew increasingly prominent. Scholar-physicians and hereditary doctors turned away from cold damage treatments. The shift from a universal medical doctrine (based on orthodox cold damage therapy) to regional medical traditions (dealing with hot factor epidemic diseases) began in the seventeenth and eighteenth centuries.[15]

New Accounts of the Qing Revival of Ancient Chinese Mathematics

During the Kangxi revival of interest in mathematics, a large-scale effort to recover and collate the treasures of ancient Chinese mathematics became an important part of the late-eighteenth- and early-nineteenth-century upsurge in evidential studies. In addition to evidential scholars who stressed mathematics in their research, a number of mathematicians who were also active in evidential studies edited ancient mathematical texts and digested European mathematical knowledge. They collated many of the mathematical texts under imperial auspices during the last years of the Kangxi reign, when the massive *Synthesis of Books and Illustrations Past and Present* (*Gujin tushu jicheng* 古今圖書集成) encyclopedia was also completed.[16]

When the first set of the Qianlong Imperial Library collection was completed between 1773 and 1781, several older, lost mathematical texts were recopied from the early Ming *Great Compendium of the Yongle reign* (*Yongle dadian* 永樂大典, 1402–25), which had survived in the imperial court. The general catalog of the Imperial Library, for example, included twenty-five notices on mathematics. The eighteenth-century search for ancient mathematical works extended beyond the borders of the Qing dynasty. The role of the Chosŏn 朝鮮in Korea and Tokugawa 德川in Japan in preserving lost Chinese works is noteworthy. A special edition of seven of the Ten Mathematical Classics was reprinted by the Imperial Printing Office 武英殿. Traditional mathematical works were also reprinted in several important collectanea.[17]

Subsequently, collation of the Ten Mathematical Classics 算經十書 accelerated after the 1728 publication of mathematical texts in the *Synthesis of Books and Illustrations* encyclopedia. The celebrity that Mei Wending梅文鼎 (1633–1721) had achieved as a mathematician, coupled with the publication of several new European mathematical works during the late Kangxi reign, brought mathematical astronomy into the mainstream of classical studies. Scholars associated with evidential studies rediscovered the Chinese origins of Western mathematics. While serving on the Imperial Library staff in the 1770s, Dai Zhen 戴震 (1724–77) collated seven of the Ten Mathematics Classics from the *Great Compendium of the Yongle Era.* In addition, he recovered two more from manuscript copies originally held by the Mao publishing family. The Imperial Printing Office then published them as rare editions.

Qing Recovery of Song-Yuan Mathematical Works

Reconstructions of the single unknown's (*tianyuan shu* 天元術) and four unknowns' (*siyuan shu* 四元術) techniques for solving polynomial equations in several unknowns and to several powers were particularly prominent in the late Qianlong era. Qin Jiushao's秦九韶 (ca. 1202–61) *Computational Techniques in Nine Chapters* (*Shushu jiuzhang*數書九章, 1247), for example, provided general algorithms for solving the Chinese remainder problem. He also investigated techniques similar to the Horner-Ruffini method devised in the early nineteenth century for calculating the roots of polynomial equations.[18]

Such works energized late Qing evidential scholars who found in it a Chinese algebra 借根方 for extracting roots using counting rods that predated the Jesuits' "borrowing roots" 借根 approach. Zhu's polynomial equations went beyond the second and third degrees up to the fourteenth. These works also provided important clues about the fundamentals of Song-Yuan polynomial algebra. Chinese classical scholars at the cutting edge of evidential studies grasped the importance of advanced algebraic techniques for solving complicated equations based on sophisticated mathematical problems. At the same time, however, they focused on the recovery of ancient texts. When Protestants finally introduced differential and integral calculus in the middle of the nineteenth century, Li Shanlan (1811–82) and others appreciated its sophistication because they had already mastered single-unknown and four-unknowns problem-solving skills.[19]

Two types of experts emerged: (1) specialists in computational astronomy and (2) literati with an academic interest in mathematics. From the angle of the cultural hierarchy then in place, which paralleled the social and political hierarchies, Qing literati justified natural studies as the proper concern of the scholar-official precisely because they included them in the classical system. Experts, as long as they were subordinate to dynastic orthodoxy and its official representatives, were necessary parts of the cultural, political, and social hierarchies.

Qing dynasty literati thus were increasingly conversant with mathematics before the Opium War. Due to their mastery of Jesuit algebra and native techniques, they generally appreciated both. Literati mathematicians were still few in number, however, and they lacked a Newtonian mechanics to find practical applications outside the domains of astronomy and cartography. Evidential scholars in the eighteenth century were not doomed to a lack of curiosity about the natural world or mathematics, but the philological biases that dominated their scholarship did not independently support the nascent research and experimentation required in the step-by-step quantification of the natural world. In light of the important place mathematics and astronomy occupied in evidential research, it is remarkable how quickly—though not overnight to be sure—the Chinese people adapted to the needs of science and technology.

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 and other Chinese mathematicians admitted that although the "four-unknowns" notation 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.

The Historiography of Modern Science in Late Qing China

Even after the Opium War (1839–42), 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 antigentry discontents who took advantage of a demographic catastrophe when 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 Protestant missions to the reforming Qing state and its new Western-oriented policies and institutions.[20]

Dr. Benjamin Hobson (1816–73) 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 science with the Chinese tradition of "broad learning about things" (*bowu*). The missionary community preferred calling science "the investigation of things and extension of knowledge" 格物致知 in its scientific translations for the Inkstone Press (Mohai shuguan).[21]

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 *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 when Hobson translated Western medical works into classical Chinese, the heat factor tradition for dealing with fever-inducing illnesses that had emerged in the seventeenth century grew 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.[22]

Chinese accepted anatomy when they could assimilate it within their focus on internal conduits of *qi.* 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.[23]

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 discussion of warm versus cold factor illnesses. Chinese physicians began to explain the wasting of the body's natural vitality in terms of tuberculosis (wasting disease) and gonorrhea (depletion illness). Western public procedures also began to be enacted in the coastal treaty ports.[24]

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.[25]

The translations Hobson prepared led some literati to question traditional Chinese medicine in the nineteenth century, however. Xu Shou (1818–84), one of John Fryer's collaborators, 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 the 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 secure.[26]

The Turn 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. The textbook presented the fifty-six elements, but Hobson presented God as the ultimate creator behind all the myriad changes in things. Although it was later changed, Hobson's chemical terminology presented the names of gases in Chinese, as well as the chemical makeup of the world, which supplanted the four-elements theory of the Jesuits and challenged the Chinese notion of the five phases.[27]

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 go over Jesuit works on mathematics and astronomy. They used Hobson's *Treatise* to catch up with findings since the days of 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 (1811–72), to work in the newly established Anqing Arsenal. Hua began translation projects with Alexander Wylie and Joseph Edkins (1823–1905), while Xu worked on constructing a steamboat based on Hobson's diagrams.[28]

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 members of a distinguished missionary community. They worked with outstanding Chinese scholars who had moved to Shanghai after failing to gain a place in the imperial civil examinations. In the 1850s Protestant journals published in Chinese, such as the *Shanghae Serial* (*Liuhe congtan* 六合叢談) at Inkstone Press, introduced new fields in the Western sciences. Beginning with the *Shanghae Serial*, the literati notion of investigating things moved from encompassing classical learning and natural studies to designating a specific domain of knowledge within the natural sciences. 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 ceased publication. Wylie made some remarkable inquiries about Chinese science and mathematics with the help of Li Shanlan. Through this interaction, Li successfully completed the transition from the traditional craft of algebra to understanding the modern calculus. Wylie and Li's 1859 translation of John Herschel's (1792–1871) *The Outline of Astronomy* (1851) grew out of their early collaboration. Cambridge educated, Herschel's astronomy moved away from the late-eighteenth-century Newtonians who had stressed geometric 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" (i.e., 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.

Many Chinese literati saw in Western learning and the modern sciences an alternative route to fame and fortune. Literati whom the Protestants trained in the sciences began to establish links with the ruling dynasty by serving as official advisers and translators after the devastations of the Taiping Rebellion. Many Chinese who had worked for Inkstone Press in Shanghai, for example, moved from the Protestant missions to the dynasty's arsenals and new schools. Protestant missionaries also worked in the Translation Department of the Jiangnan Arsenal after it was established in Shanghai. This reminds us of the Jesuits who had changed their focus from proselytizing among Chinese. Like the Jesuits, the Protestants remained committed to the gospel of science in China because they also thought its success in government would redound to Christianity.

In the 1860s the Qing government employed many missionaries as translators to work with Chinese in the Qing dynasty's Jiangnan Arsenal. A small coterie of exceptional Chinese literati also joined the translation project as editors and proofreaders. 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 同文館. Literati who feared that Western learning would subvert state orthodoxy produced several major nineteenth-century anti-Christian tracts. 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. Yung had advised Zeng in 1863 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 1867–68 along with some British machinists. By 1869 Nanjing was producing rockets and trying to forge larger guns.

In 1866 the Hunanese general Zuo Zongtang 左宗棠 (1812–85) suggested creating a modern naval yard in Fuzhou, Fujian, to build and operate Western-style warships. The regents of the Tongzhi emperor (r. 1862–74) quickly authorized the proposal. When Zuo was sent on military campaigns to Chinese Turkestan (Xinjiang) to put down rebellions, Shen Baozhen 沈葆禎 (1820–79) became the director-general of the Fuzhou Naval Yard 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 1884–85, Fuzhou remained a major center of French interests.[29]

Subsequently, in 1866–67, 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 was successfully opposed in the 1870s, but Li's mathematics examinations at the School of Foreign Languages were influential.

New Accounts of Industrialization in the Jiangnan Arsenal and Fuzhou Naval Yard

The Qing government also established the Jiangnan Machine Manufacturing General Bureau, usually called the Jiangnan Arsenal, 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) a school for training skilled workmen, and (4) a machine shop. In addition, the Jiangnan Arsenal had thirteen branch factories. By 1892 it occupied 73 acres of land, with 1,974 workshops and a total of 2,982 workers. The arsenal acquired 1,037 sets of machines and produced 47 kinds of machinery under the watch of foreign technicians who supervised production. From 1868 to 1876, shipbuilding in the Jiangnan Arsenal was highly productive. It built 11 ships in 8 years. Ten were warships. Five of these had wooden hulls, the other 5 iron hulls. All parts of each ship, including the engine, were built at the arsenal. When compared to the warships built following French models at the leading Japanese dockyard in Yokosuka in the 1870s, the level of shipbuilding technology at the Jiangnan Arsenal was actually earlier and higher.[30]

Besides the Jiangnan Arsenal, the second major industrial site for shipbuilding and training in engineering and technology was the Fuzhou Naval Yard. When Zuo Zongtang submitted his 1866 memorial to establish a complete naval yard at Fuzhou he expected that after five years he could eliminate the need for foreign experts. In return those provinces would receive naval protection from the Southern Fleet based at Fuzhou. Zuo and his successor, Shen Baozhen, relied mainly on French expertise at Fuzhou. Once the Qing established the naval yard, however, the Fujian Maritime Customs left the venture in a perpetual financial bind. At its peak the shipyard employed 3,000 workers. When later construction was completed the force dropped to 1,900, with 600 in the dockyard, 800 in workshops, and 500 manual laborers. The naval yard had more than 45 buildings on 118 acres set aside for administrative, educational, and production purposes.

In terms of scale, the Fuzhou Naval Yard 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 were planned with 80 to 250 horsepower engines. Of these, thirteen would be transport ships with 150 horsepower engines. Sixteen ships were finished during this time. Ten transports with 100 horsepower engines, as well as one corvette as a showpiece with a 250 horsepower engine, were built in 1869–75. After 1874 the Naval Yard sent graduates to Europe, especially England and France, for advanced training.[31]

Unfortunately, the decisive Qing defeat in the Sino-Japanese War of 1894–95 energized public criticism of the dynasty's allegedly inadequate policies. The unexpected naval disaster at the hands of

Japan and the way it was presented as Japan's technological victory shocked many literati and officials. A greater respect for Western studies emerged in literati circles. Technology alone was not the key determinant. 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.

Although the late-nineteenth-century naval battles China lost are still used as a litmus test 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 that emerged in the eighteenth century. A new group of artisans, technicians, and engineers emerged between 1865 and 1895 whose expertise no longer depended on 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 Naval Yard. 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 in the shipyards and arsenals who later provided the manpower for China's increasing number of public and private industries in the early twentieth century.[32]

New Aspects of Modern Science in Twentieth-Century China

Recent authors have stressed the decisive role of the Chinese state in modern science. They also acknowledge, however, that such an approach misses the global and comparative issues involved in the mastery of modern science by Chinese scientists. Too often we have called attention to the political rhetoric and philosophical theory enunciated by Chinese publicists of science since the 1919 May Fourth movement. As a consequence, we have overlooked the advent of early Chinese scientists themselves as spokespersons for modern science. Others have stressed the priority of artisanal practice in the Chinese setting and have naively assumed that past Chinese successes in technology were purely practical. The problem is how best to combine both sides of these formulations, to recognize that the Chinese interest in modern science was simultaneously theoretical and practical. The widespread use of the term *keji* (science and technology) to describe contemporary "technoscience" in Chinese universities and research institutes is a case in point.

Similarly, others problematize post-Mao efforts to distinguish Chinese socialism from scientific progress. Most Euro-American and Chinese accounts have indicted Maoist mass science and its rhetoric of science's role in class struggle as a smokescreen for power politics. We have elided what socialist ideals were about during the Great Proletarian Cultural Revolution from 1966 to 1976. Although the victimization of many scientists during this period and the role of Maoist ideology in leading some Chinese scientists to oppose relativity in the name of dialectical materialism, for example, are important issues in the unmasking of Maoism after 1976, the broader aspects of understanding why mass science appealed to many Chinese and some Euro-Americans in the 1960s force us to question the easy separation of scientific practice from social and political agendas. More researchers in socialist laboratories will reveal the peculiar nature of socialist rhetoric and Communist institutions in forging myths about science that enhance its revolutionary status in China and elsewhere in the increasingly postsocialist world. After all, liberal capitalist ideals informed our own Euro-American notions of modern science as the sine qua non for the rise of the middle classes via science and engineering since the Industrial Revolution.[33]

This account, taken as a whole, suggests a number of ways in which a comparative history of science can lead us in new directions. First and foremost, historicizing the Western scientific revolution in a global context makes it possible to compare other, non-Western approaches to modern science without reducing such efforts to simple reception history. Second, differential studies that wield appropriate concepts and categories for comparing precise historical situations are mandatory. In particular, case studies can successfully integrate scientific content and historically dynamic contexts as the key to moving from the local to the global and back again. We should explore Chinese interests in modern science as scientists there articulated and practiced them rather than speculating about why they did not act the way Americans and Europeans expected them to act. Future research on the active careers of modern Chinese scientists, both individually and as a group, will allow us to supersede past accounts of the passive reception history of modern science in China.

Many others—including scientists—protested such May Fourth iconoclasm, however. One by-product of the Republican government's increasing involvement in public health, for instance, was that Western-style physicians and classically trained Chinese doctors organized into separate medical associations. They drew the state into a contest over whose medical theory and practices were legitimate. The Republican state initially was tied to Western medical theories and institutions, while Western-style doctors controlled the new Ministry of Public Health. When the Guomindang-sponsored Health Commission proposed abolishing classical Chinese medicine (Zhongyi) in February 1929, however, traditional Chinese doctors immediately responded by calling for a national convention in Shanghai on March 17, 1929, which was supported by a strike in pharmacies and surgeries nationwide. The protest succeeded in getting the proposed abolition withdrawn, and the Institute for National Medicine (Guoyi guan) was subsequently established. After 1929 the government established two parallel but politically and educationally distinct institutions, one Western and one Chinese. This dichotomy should not be overemphasized, since "traditional Chinese medicine" as it is practiced today represents an active response to the inroads of modern Western medicine, but this division has survived both the Guomindang Republic and the Communist People's Republic.

If there has been one constant in China since the middle of the nineteenth century, it is that imperial reformers, early Republicans, and Chinese Communists have all prioritized modern science and technology. We can no longer afford to undervalue the place of science in modern and contemporary China. China's plans to send space expeditions to the moon and Mars in the twenty-first century are in part a response to the shock of heavy-handed Western and Japanese imperialism since 1850. It is therefore important that the role of modern science, technology, and medicine in contemporary China is properly understood not only by historians of science.

Notes

Benjamin Elman (PhD, University of Pennsylvania, 1980) is Gordon Wu '58 Professor of Chinese Studies, Princeton University, 2011-. His teaching and research fields include (1) Chinese intellectual and cultural history, 1000–1900; (2) the history of science in China, 1600–1930; (3) the history of education in late imperial China; and (4) Sino-Japanese cultural history, 1600–1850. His publications include *From Philosophy to Philology* (1984, 1990, 2001), *Classicism, Politics, and Kinship* (1990), and *A Cultural History of Civil Examinations in Late Imperial China* (2000). More recent books are *On Their Own Terms: Science in China, 1550–1900* (2005) and *A Cultural History of Modern Science in Late Imperial China* (2006). Since a sabbatical leave in 2007–8, which was supported by a research fellowship from the American Council of Learned Societies, he has continued working on a new project entitled "The Intellectual Impact of Late Imperial Chinese Classicism, Medicine, and Science in Tokugawa Japan, 1700–1850," under the auspices of summer 2008 and 2009 research grants from the Chiang Ching Kuo Foundation in Taiwan.

This article was written in June 2011.

[1] See the articles collected in "Focus: Science and Modern China—New Directions in the History of Modern Science in China," special issue, *ISIS* 98 (2007): 517–83.

[2] Joseph Needham, *Science and Civilisation in China,* multiple volumes (Cambridge: Cambridge University Press, 1959). Nathan Sivin redirected this approach to include successful Chinese developments in astronomy. See his "Why the Scientific Revolution Did Not Take Place in China—or Didn't It?," *Chinese Science* 5 (1982): 45–66. Compare Roger Hart, "Beyond Science and Civilization: A Post-Needham Critique," *East Asian Science, Technology, and Medicine* 16 (1999): 88–114.

[3] Bruno Latour, *Science in Action: How to Follow Scientists and Engineers through Society* (Cambridge, MA: Harvard University Press, 1987).

[4] Chu Pingyi, "Remembering Our Grand Tradition: The Historical Memory of the Scientific Exchanges between China and Europe," *History of Science* 41 (2003): 194–99.

[5] Benjamin Elman, "Jesuit Scientia and Natural Studies in Late Imperial China," *Journal of Early Modern History: Contacts, Comparisons, Contrasts* 6.3 (Fall 2002): 209–32. See also Hu Minghui, "Provenance in Contest: Searching for the Origins of Jesuit Astronomy in Early Qing China, 1664–1705," *International History Review* 24.1 (March 2002): 1–36.

[6] Nathan Sivin, "Copernicus in China," in *Colloquia Copernica II: Etudes sur l'audience de la theorie heliocentrique* (Warsaw: Union Internationale d' Historie et Philosophie des Sciences, 1973), 63–122.

[7] Benjamin A. Elman, "Global Science and Comparative History: Jesuits, Science, and Philology in China and Europe, 1550–1850," *East Asian Science, Technology, and Medicine* 26 (2007): 9–16.

[8] Tian Miao, "*Jiegenfang, Tianyuan,* and Algebra in Qing China," *Historia Scientiarum* 9.1 (1999): 101–19.

[9] Benjamin A. Elman, *From Philosophy to Philology: Social and Intellectual Aspects of Change in Late Imperial China,* UCLA Asian Monographs (Los Angeles: UCLA Asia Institute: 2001).

[10] Roger Hahn, *The Anatomy of a Scientific Institution: The Paris Academy of Sciences, 1666–1803* (Berkeley: University of California Press, 1971), 275–85.

[11] Nathan Sivin, *Traditional Medicine in Contemporary China* (Ann Arbor: Center for Chinese Studies, University Michigan, 1987). See also Charlotte Furth, *A Flourishing Yin: Gender in China's Medical History, 960–1665* (Berkeley: University of California Press, 1999).

[12] Shigehisa Kuriyama, *The Expressiveness of the Body and the Divergence of Greek and Chinese Medicine* (New York: Zone Books, 1999).

[13] Chao, Yuan-ling. "Medicine and Society in Late Imperial China: A Study of Physicians in Suzhou" (PhD diss., Department of History, UCLA, 1995).

[14] Joanna Grant, *A Chinese Physician: Wang Ji and the "Stone Mountain Medical Case Histories"* (London: Routledge Curzon, 2003).

[15] Marta Hanson, "The *Golden Mirror* in the Imperial Court of the Qianlong Emperor, 1739–1743," *Early Science and Medicine*, 8, 2 (2003): 112–47.

[16] Jean-Claude Martzloff, *A History of Chinese Mathematics*, trans. Stephen Wilson (New York: Springer-Verlag, 1997).

[17] Ken'ichi Sato, "Reevaluaton of *Tengenjutsu* or *Tianyuanshu* in the Context of a Comparison between China and Japan," *Historia Scientiarum* 5.1 (1995): 59–60.

[18] Ulrich Libbrecht, *Chinese Mathematics in the Thirteenth Century: The Shu-shu Chiu-chang of Ch'in Chiu-shao* (Cambridge, MA: MIT Press, 1973).

[19] Horng, Wann-sheng. "Li Shan-lan: The Impact of Western Mathematics in China during the Late Nineteenth Century" (PhD diss. in history, City University of New York, 1991).

[20] Knight Biggerstaff, *The Earliest Modern Government Schools in China* (Ithaca: Cornell University Press, 1961).

[21] David Wright, *Translating Science: The Transmission of Western Chemistry into Late Imperial China, 1840–1900* (Leiden: E. J. Brill, 2000).

[22] Marta Hanson, "Robust Northerners and Delicate Southerners: The Nineteenth-Century Invention of a Southern Medical Tradition," *positions* 6.3 (Winter 1998): 548.

[23] Warwick Anderson, "Immunities of Empire: Race, Disease, and the New Tropical Medicine, 1900–1920," *Bulletin of the History of Medicine* 70.1 (1996): 94–118.

[24] Ruth Rogaski, *Hygienic Modernity: Meanings of Health and Disease in Treaty-Port China* (Berkeley: University of California Press, 2004).

[25] Chang Chia-feng, "Aspects of Smallpox and Its Significance in Chinese History" (PhD diss. in history, London University, 1996).

[26] Yi-li Wu, "Transmitted Secrets: The Doctors of the Lower Yangzi Region and Popular Gynecology in Late Imperial China" (PhD diss. in history, Yale University, 1998).

[27] Bridie Andrews, "Tailoring Tradition: The Impact of Modern Medicine on Traditional Chinese Medicine, 1887–1937," in Viviane Alleton and Alexeï Volkov, eds., *Notions et Perceptions du Changement en Chine.* Paris: Collège de France, Institut des Hautes Études Chinoises, 1994, 149–66.

[28] Adrian Bennett, *John Fryer: The Introduction of Western Science and Technology into Nineteenth-Century China* (Cambridge, MA: Harvard University Research Center, 1967).

[29] David Pong, *Shen Pao-chen and China's Modernization in the Nineteenth Century* (Cambridge: Cambridge University Press, 1994).

[30] Meng Yue, "Hybrid Science versus Modernity: The Practice of the *Jiangnan Arsenal,* 1864–1897," *East Asian Science, Medicine, and Technology* 16 (1999): 7–43.

[31] Pong, *Shen Pao-Chen and China's Modernization in the Nineteenth Century.*

[32] Benjamin A. Elman, *A Cultural History of Modern Science in China* (Cambridge, MA: Harvard University Press, 2006), chaps. 6–7.

[33] See "Focus: Science and Modern China."