REASSESSING THE NEEDHAM QUESTION: WHAT FORCES IMPEDED THE DEVELOPMENT OF MODERN SCIENCE IN CHINA AFTER THE 15TH CENTURY?

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Abstract

Why did modern science not develop in China, despite the fact that up until the 15th century, ancient China led the West for over a millennium in scientific discovery and technological advancement? This is the so-called "Needham Question," named after Joseph Needham (1900-1995), a brilliant Cambridge Sinologist, biochemist and historian of science who first posed the question in the 1940s. This essay will analyze Needham's own answer to this question, as well as the main theories that offer historical, philosophical, political, economic, and cultural perspectives on the paradox. It will also assess the relevance of The Needham Question to the study of the history of science and technology, particularly in the context of China's astonishing re-emergence as a global economic and political power.

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Introduction

Writing in 1620, the English philosopher Francis Bacon proclaimed the three greatest interventions in world history to be printing, gunpowder and the compass. According to Bacon:

> These three have changed the whole face and state of things throughout the world; the first in literature, the second in warfare, the third in navigation; whence have followed innumerable changes, in so much that no empire, no sect, no star seems to have exerted greater power and influence in human affairs than these mechanical discoveries.[1]

Not surprisingly for a man of his era, Bacon presumed that these inventions had originated in Europe. It was not until the end of World War II, however, that a relatively obscure English scientist from Cambridge University revealed that all three inventions identified by Bacon, and indeed, hundreds of other scientific, mathematical and technological discoveries had emanated from China. The scientist was Joseph Needham (1900-1995), a tall, brilliantly erudite and eccentric biochemist obsessed with the history, language, science, and civilization of China.

Needham's revelations were nothing short of stunning. At the time, many in the West looked down upon modern China as a backward, impoverished and illiterate nation. The Jesuits, who first entered China in the late 16th century, opened the West to many of the marvels of Chinese civilization. However, these were largely confined to the fine silk and ceramic products produced by Ming Dynasty artisans, and the rich texts of the Confucian canon.[2] Scientific prowess was not something Westerners commonly attributed to the Chinese people.

Not until the appearance of the British scholar did the world begin to comprehend the breadth and significance of China's contributions. In the remaining five decades of his life, Needham would co-author the largest, most definitive compendium of the history of Chinese science and technology ever produced.

Science and Civilization in China, first published in 1954, comprises 24 volumes and documents the origins of over a thousand agricultural, astronomical, chemical, engineering, mathematical, medical, metallurgical, and military discoveries and inventions. Described by fellow Cambridge scientist and Sinologist Laurence Picken as "perhaps the greatest single act of historical synthesis and intercultural communication ever attempted by one man," *Science and Civilization in China* is an astonishing encyclopedia of creativity and genius, and opened not only the Western world to ancient China's brilliant scientific history, but also Chinese eyes to the glory of over two millennia of invention.[3]

Over the course of his remarkable discoveries, Needham continued to be perplexed by one question: Why, given the magnificent inventions of its long and ancient past, did scientific development in China come to an abrupt halt around 1500? Why did the scientific revolution of the 16th century and the industrial revolution of the late 18th century occur in Europe and Britain, but not in China? China had for over a millennium been far more advanced in science, engineering, and medicine than the West; but sometime around 1500, this innovation suddenly stopped, seemingly without reason. Needham became so obsessed with this question and its many possible answers that he devoted much of the second half of his life to addressing it. It became known as "The Needham Question," and scientists and historians of science from around the world have put forth a variety of possible answers to help understand what happened in China, particularly in comparison with the western world.

Needham's Introduction to China

Following Great Britain's entry into World War II, China desperately sought the British government's support for its academic institutions, scholars, and scientist, all under siege by Japanese occupation forces. The Nationalist Chinese were particularly keen to salvage key documents and archives relating to strategic

scientific, medical and technological know-how. In response, the British Commonwealth and Foreign Office established the Sino-British Scientific Cooperation Office and cast a net to find a qualified director.[4] Needham, a Sinophile fluent in Chinese, immediately applied for the position and in late 1942, found himself fulfilling a lifetime dream. He arrived in early 1943 in Kunming, in southwestern Yunnan Province, and proceeded onwards to the wartime capital city of Chongqing, where he remained stationed until 1946.

Over this three-year period, Needham travelled across non-occupied China, conducting 11 expeditions and collecting a cornucopia of scientific data. Through observation, investigation and meticulous research, he uncovered proof of the origins of more than 1,000 inventions, devices, processes, and compounds, many of which had until then been attributed to western science. In 1945, Needham published his main findings, including the origins of the printing press, gunpowder and magnetic compass, in his book, *Chinese Science*.[5]

Science and Civilization in China (SCC)

Returning to Cambridge in 1948, Needham soon submitted a proposal to Cambridge University Press to publish a definitive account of his findings in China. The original proposal, dated 15 May 1948, envisaged a one-volume treatise entitled "Science and Civilization in China."[6] Needham noted two objectives in his proposal: first, to present a complete history of science and technology in China; and second, to explain China's contribution to the history of world science and civilization.[7] Cambridge University Press immediately approved funding for the project, and just as quickly, Needham realized that the scope of his book could not possibly be contained within a single volume. The first volume appeared in 1954, and by the time of his death in 1995, *Science and Civilization in China* had grown to 15 volumes.

Even Needham's most discerning critics were astounded by *Science and Civilization in China*. Eminent British scientist Professor Mansel Davies wrote:

> [SCC] is perhaps the greatest work of scholarship achieved by one individual since Aristotle….Needham himself wrote more than 12 volumes….The first 10 volumes alone have 4,808 text pages, 1,202 illustrations, 1,285 bibliographies, and 549 index pages (in Chinese and Roman script). Whilst the size of the work is itself remarkable, it is the thoroughness, the depth, and the enlightenment found in these volumes which make them an unsurpassed historiographic treasure of the 20th century. Carefully detailed, systematic accounts and interpretations of Chinese achievements over 25 centuries in mathematics and astronomy, physics, chemistry, geology, zoology, botany, hydraulics, metallurgy, maritime science, textiles, hygiene, and medicine are presented.[8]

Needham passionately believed in the importance of framing his work in the context of world civilization. Dr. Gregory Blue, who was Needham's research assistant from 1977 to 1990, quotes Needham:

> One of the greatest needs of the world in our time is the growth and widespread dissemination of a true historical perspective, for without it whole peoples can make the gravest misjudgments about each other. Since science and its application dominate so much of our present world, since men of every race and culture take so great a pride in man's understanding and control over her, it matters vitally to know how much modern science came into being. Was it purely a product of the genius of Europe, or did all civilizations bring their contributions to the common pool? A right historical perspective here is one of the most urgent necessities of our time.[9]

SCC currently comprises 24 volumes, with three additional volumes under preparation. Remarkably, it is still an active project at the Needham Research Institute at Cambridge, over six decades since its inception.

Scientific Development in Ancient China (circa. 400-1500)

It is important to understand the magnitude of scientific innovation in ancient China and compare it to the state of science and technology in Europe during similar periods. The Chinese

have long appreciated the wonders of their storied past. The centerpiece of the magnificent opening ceremony of the 2008 Beijing Olympics was the depiction of the *si da fa ming* (the "Four Great Inventions of Ancient China"), namely the magnetic compass, gunpowder, papermaking, and printing. Showcasing scientific achievement was a metaphor not lost on the Chinese people, who embrace China's new-found pride and respect in the 21st century with excitement and confidence.

The scope of pre-modern Chinese scientific invention is breathtaking. In the fields of mathematics, physics, chemistry, biology, astronomy, medicine, metallurgy, and engineering (civil, mechanical, hydraulic, agricultural, and nautical), these discoveries ranged from transformational inventions such as the abacus, acupuncture, ball bearings, the blast furnace, calipers, cast iron, the mechanical clock, the horse collar harness, the iron plough, plant grafting, the propeller, to more prosaic—but no less ingenious—inventions such as matches, the toothbrush, folding umbrellas and perfumed toilet paper.[10] As Needham wrote, "the mere fact of seeing them listed brings home to one the astonishing inventiveness of the Chinese people."[11]

Needham's genius was to catalog, verify and document the origins of these achievements, large and small, in a manner that allowed Westerners and Chinese to recognize the brilliance of centuries of applied creativity. The table below shows a sample from *Science and Civilization of China*, reflecting a range of mechanical inventions and techniques that originated in China, with the approximate lag time (in centuries) in technology transfer to Europe. The results are startling:

Invention	China's Advancement over Europe (in centuries)
Rotary fan	14
Crossbow	13
Porcelain	11-13
Iron chain suspension bridge	10-13
Canal lock gates	12
Cast iron	10-12
Wagon mill	12
Magnetic compass	11
Paper	10
Wheelbarrow	9-10
Arched bridge	7
Gunpowder	5-6
Movable type printing	4

Source: *Science and Civilization in China*, Vol. 1, p. 242

Needham was able to identify several hundred examples of inventions from China that predated their first appearance in Europe. As Blue remarks, it is interesting to note that in contrast, the West was only able to contribute two mechanical elements to Chinese civilization at the time of the Jesuit missions in the 17th century, namely the Archimedean screw and the crankshaft.[12] Needham's work clearly demonstrates that from the 400 to 1500, levels of science and technology in Chinese civilization far exceeded those of Europe.

Needham puts his findings into perspective:

> If…the Chinese were recording sunspot cycles a millennium and a half before Europeans noted the existence of such blemishes on the solar orb, if every component of the parhelic system received a technical name a thousand years before the Europeans began to study them, and if that key instrument of scientific revolution, the mechanical clock, began its career in early 8th century China rather than (as is usually supposed) in 14th century Europe, there must be something wrong with conventional ideas about the uniquely scientific genius of Western civilization.[13]

Needham's Response to the Question

As Needham began to uncover the ingenuity of ancient China's science and technology, the question which took on his name started to intrigue him. He addressed the question explicitly in his 1969 book, *The Grand Titration: Science and Society in East and West*.[14] He determined that there were two main reasons why Chinese science failed to modernize. The first had to do with the central influence of Confucianism and Taoism in Chinese culture, particularly informing attitudes toward nature and science amongst the educated elite. Confucianism, or more precisely the Neo-Confucian school which emerged dominant in the Song Dynasty (960-1279), was an ethical system emphasizing an inward-looking, mind-focused way of life. Social harmony, happiness and goodness arose from people developing a set of virtues that underlay everyday conduct. Such virtues included filial piety, veneration of ancestors, respect for elders, moderation and conformity of the individual to society.[15] Needham argued that this inward focus marginalized the importance of studying the natural world. In fact, it rendered science frivolous in the grander scheme of what mattered most in life.

Needham felt that Taoism also had a negative impact on the development of the scientific method in China. Taoism stresses love of and respect for nature. As a code of behavior, it teaches that man should leave nature alone—completely—and accept its way, whatever the consequences.[16] The external world is far too complex to be fathomed by analysis, observation or mathematical theories. Originating more than 2,000 years ago, Taoism received official status as a religion during the Tang Dynasty (618-907).[17] Needham believed that its *laissez-faire* attitude toward the natural world proved a cultural and intellectual inhibitor to scientific research and innovation:

> It was not that there was no order in nature for the Chinese, but rather that it was not an order ordained by a rational personal being, and hence there was no conviction that rational personal beings would be able to spell out in their lesser earthly languages the divine code of laws which had been decreed aforetime. The Taoists, indeed, would have scorned such an idea as being too naïve for the subtlety and complexity of the universe as they intuited it.[18]

Secondly, Needham argued that modern science failed to develop in China because China lacked the kind of merchant-capitalist system that had been developing in Europe from the late Middle Ages to the Age of Discovery. Needham observed that China had started to lag in scientific innovation during this period.[19] He concluded that without a broad-based system of economic incentives, applied scientific research and development would be haphazard at best. Writing in *Science and Civilization in China*, Needham declared that:

> Interest in Nature was not enough, controlled experimentation was not enough, empirical induction was not enough, eclipse-prediction and calendar calculation were not enough—all of these the Chinese had. Apparently, only a mercantile culture alone was able to do what agrarian bureaucratic civilization could not—bring fusion-point to the formerly separated disciplines of mathematics and nature-knowledge.[20]

Since Needham first raised his question, there have been a multitude of theories attempting to resolve the puzzle. It is somewhat ironic that this question, which absorbed and perplexed Needham's great mind for decades, elicited even more elaborate and sophisticated answers from lesser scientists and historians of science than from the originator himself.

Philosophical Influences on Needham

The 20th century Chinese philosopher Yu-Lan Fung (*Feng Yulan*) had a great influence on Needham's thinking about Confucianism and Taoism.[21] In his seminal 1922 essay "Why China Has No Science," Fung argued that science, in the Anglo-Saxon sense of the term, had no place in China "because the Chinese concern themselves solely with the mind, whereas Europeans concern themselves with knowing and controlling matter."[22] He explained that since the Song Dynasty in the 10th century, the

Chinese mind has been shaped by the forces of Confucianism, Taoism, and Buddhism. This so-called "Neo-Confucianism" continues to form the essence of Chinese philosophy today. Its basic tenet is that all conduct should be focused inward on the mind, and that happiness and meaning come from within. Fung wrote that the Chinese had no need for science *per se*: "They had no need or interest in analyzing the external world because it was their minds that they wished to conquer and nothing else."[23] Fung noted that in contrast, Descartes and Bacon, the two great philosophers of western science, had distinct notions of the purposes of science: "Descartes said that it is for certainty; Bacon said that it is for power."[24]

According to Fung, the Taoist belief that there is only one certainty, which is that nature holds all goodness and virtue, negated any need for scientific certainty. Confucians, in turn, had no need for scientific certainty since they sought to know only themselves within the context of self-reflection and discovery. They had no need for scientific power because there was no external force they wished or needed to conquer.[25] Moreover, Confucians could see no use in science if "intellectual certainty and the power to conquer the external world are not included in the idea of good."[26] This overview reveals the key differences between the Chinese and European philosophies of science, and their bearing on The Needham Question. Fung maintained that Europeans were focused on the external world, the world of the atoms, the human body, structures, tools, and weapons. In contrast, the Neo-Confucians, heavily influenced by Taoist and Buddhist thinking (the latter even treats the "external world" as an illusion), believe that everything good is already within each person for eternity. So there is no use in searching externally for certainty, power, meaning, happiness, or logic.

In short, the Neo-Confucian beliefs that have dominated Chinese culture, politics and society for over 1,000 years hold that scientific methods and inventions designed to harness nature are fruitless exercises that detract from the pursuit of happiness and goodness. As literary critic Kenneth Rexroth noted in his review of *Science and Civilization in China*, Vol. 4:

> Chinese science…is radically, fundamentally different, and demands a willed, sympathetic reorientation of perspective on the nature of nature….Chinese scientific thought has been far more organic than mechanical, permissive than authoritarian in its interpretation of Nature's ways.[27]

Needham himself wrote that Chinese science:

> …derives from a world in which Nature works by "doing nothing" instead of by passing laws, in which the universe moves as a great web of interrelatedness of which man and his imperatives are only a part. That is basically a true picture of the Chinese universe. It is a universe of strange and wonderful things. It is a universe Western man is going to have to understand if we are going to survive happily together on a planet where, whether we like it or not, as Confucius said, 'all men are brothers.'[28]

The main problem with the arguments of Fung and Needham is that they cannot explain the stunning advances in science and technology which the Chinese produced from the Song Dynasty to end of the 15th century. In fact the Song period was one of the richest in terms of scientific discovery and inventiveness. By the end of the 11th century, China had coal-burning blast furnaces and produced twice as much pig iron as England did at the height of the Industrial Revolution.[29] The output of coal reached 150,000 tons and per capita income was estimated to be more than five times that of Europe.[30] China produced the most sophisticated textiles in the world at that time. Shen Kuo (1031-1095) and Su Song (1020-1101), two of the greatest scientists and inventors in Chinese history, lived during the Song period.

In the 13th century, a water-powered spinning machine similar to those used in Europe around 1700 was already producing linen thread.[31] China's sophisticated agriculture, industry and commerce astonished Marco Polo, whose native Venice was considered one of the most prosperous cities in Europe at the time. Following the Song era, key inventions included smallpox inoculation, the spindle wheel, bronze type printing, gunpowder, the trebuchet and bombs (12th century); lacquer and pasteurization of wine (13th century); sand clocks, rockets and rocket launchers (14th century), wallpaper and toilet paper (16th century) and the ginning machine (17th century).[32]

In reality, Neo-Confucianism's influence on impeding the development of science and technology in China lay not so much in its philosophical teachers *per se*, but in its enormous influence on the imperial civil service examination system.

The Imperial Civil Service Examination System

A number of scholars, most notably the economic historian Justin Yifu Lin, have argued that the root of The Needham Question lies in the nature and influence of the imperial civil service examination. This formidable system determined bureaucratic appointment and advancement from the 7th century to the beginning of the 20th century.[33] The examinations emphasized mastery of the Confucian canon and its attendant virtues to the near exclusion of mathematical and scientific study. Positions in the imperial bureaucracy conferred much sought-after power, social status and wealth; as a result, the civil service examinations had an enormous impact on the education of the elite. Lin's argument is that preparation for these examinations entailed at least two decades of intense study and "crowded out" any possible inquiry into non-essential subjects. The consequences of this focused academic endeavor were neglect (and official disdain) of the sciences.

In 221 BC, Emperor Qin united China and the country remained an absolute hereditary monarchy until the overthrow of the Qing Dynasty in 1911. Notwithstanding the replacement of dynastic rule first by a quasi-democratic republic and then by a Communist system, China has remained a unified country administered by a centralized bureaucracy for over 2,000 years.

One of the greatest reforms of the Qin Emperor was to establish a bureaucratic system of governance, which has remained largely intact over two millennia. An elaborate pyramidical structure comprising central, provincial, prefectural, county and township bureaus was formed to govern the newly united country.[34] Most importantly, Qin abolished the former hereditary-nepotistic system

of appointing government officials and replaced it with a "recommendation system," in which government officials filled vacancies by referral.[35] The hope was that officials would recommend men they considered possessed of talent and virtue. The reality, however, was that the system became corrupted, with wealthy families often buying favor for their sons and relatives.

During the Sui Dynasty (580-618), the method of civil service appointment and promotion was again reformed. The recommendation system was replaced by a fair and impartial civil service examination.[36] Government officials began to be selected and promoted on the basis of merit, namely intellectual talent and virtue. By the time of the Song Dynasty (960-1279), all bureaucrats were selected by competitive examinatin.[37] This reform proved monumental in Chinese history, and made the imperial civil service unique for centuries in its emphasis on meritocratic selection and advancement. This system continued until it was abolished in 1904, in a vain attempt to reform the dying Qing regime.[38]

Initially, the civil service examination tested a wide range of subject areas, including mathematics, astronomy and the "laws of nature."[39] In 1313, however, mathematics and science-related subjects were eliminated, and by the time of the Ming Dynasty (1368-1644), the examination tested only the Confucian classics, i.e. the humanities.[40]

One of the greatest books on the state of science and technology in pre-modern China was *A Volume on the Creations of Nature and Man: Chinese Technology in the 17th century (T'ien Kung K'ai Wu)*, written by the famous Ming scientist Song Yingxing. His lament on his own book is a sad and poignant commentary on the times: "An ambitious scholar will undoubtedly toss this book onto his desk and give it no further thought; it is a work that is in no way concerned with the art of advancement in officialdom."[41]

Matteo Ricci, the great Jesuit scholar-priest who lived and travelled across China between 1583-1610, made a similar observation:

> It is evident to everyone here that no one will labor to attain proficiency in mathematics or medicine who has any hope of becoming

> prominent in the field of philosophy. The result is that scarcely anyone devotes himself to these studies, unless he is deterred from the pursuit of what are considered to be higher studies, either by reason of family affairs or by mediocrity of talent. The study of mathematics and that of medicine are held in low esteem, because they are not fostered by honors as is the study of philosophy, to which students are attracted by the hope of the glory and the rewards attached to it.[42]

The core of the examination syllabus was the main Confucian canon, comprising *The Four Books* and *The Five Classics*.[43] These totaled over 430,000 characters and required six years of rigorous study.[44] To even quality to sit the final imperial examination, a scholar would have to pass an arduous progression of lower-level examinations. During the Ming and Qing era, these comprised preliminary, county, prefectural, academy, provincial and state examinations.[45] Competition was intense. The pass rate in the Ming era for the provincial examination was 4 percent; for the state level examination it was less than 10 percent.[46] The few who attained the vaunted status of *jinshi*, or top scholar, in the final imperial examination studied, on average, for over 25 years without pause. Only one in 3,000 examinees achieved this ranking.[47]

Historian Lin's response to The Needham Question is that for the ambitious educated classes, there was neither the time nor the incentive to study mathematics and science, or to perfect the techniques of scientific investigation, experimentation and hypothesis testing. By this reasoning, he argues that from the end of the first millennium to modern times, Chinese society never developed a scientific tradition.

It is worthwhile to consider more closely the examination's extreme emphasis on the Confucian classics. On the surface, this focus would be expected, given the dominance of Neo-Confucian thinking in society, and especially among the imperial elite. However, there was a less obvious and more ingenious rationale. According to Lin and China scholar C.K. Yang, the imperial bureaucracy for centuries remained small relative to the physical size of the country and its population because of the prevalent Confucian ethic. From the 16th century to the middle of the 17th century, the total number of Chinese government officials ranged from

10,000 to 14,000, while the population grew from 75 million to 100 million.[48] The ratio of bureaucrats to citizens in China was far lower than those in England (1:200) and France (1:280) at the time.[49] Even at the height of the Qing Dynasty in the mid 18th century, the total civil service did not exceed 40,000, within a total population of 200 million.[50]

China scholar Yang attributes the efficiency of pre-Qing government to the focus on Confucianism in the civil service examinations as well as the continuous assessment required for promotion. Imperial Chinese government placed great emphasis on the ethical virtues of its officials; magistrates and lower-level bureaucrats were expected to rule judiciously and create networks of similarly upright non-officials to provide leverage in local governance. Officials could be trusted to develop wide-ranging ties with merchants, village elders, artisan chiefs and other useful citizens to "get things done."[51] In contrast, the European civil services tended to emphasize specialization and technical skills. The Chinese civil service embodied the Confucian principles of honesty, moderation, piety, obedience, conformity, fairness and harmony. By selecting its officials on the basis of virtues rather than technical skills it was able to rule successfully with a relatively small corps of highly educated people. The continuous 2,000-year history of the Chinese bureaucracy serves as testimony to the power of this system.

Critiques of the Civil Service Examination Theory

One substantial criticism of the civil service examination theory comes from Nathan Sivin, a noted historian of Chinese science and medicine. He argues that China was not unique in creating a "scholar-bureaucrat class immersed in books, faced toward the past, and oriented toward human institutions rather toward nature."[52] He observes:

> In Europe at the onset of the Scientific Revolution, the intellectual world was filled with scholars and dons immersed in books, steeped

> in the classical Greco-Roman Judeo-Christian classics, and oriented towards the study of the humanities rather than on nature. This, however, did not prevent the great changes in scientific thinking and invention which would sweep across Europe.[53]

Sinologist and historian Derk Bodde concurred with this point, citing the state of academia in England during the early 17th century:

> Of course the Chinese situation was by no means unique in 1600. As a Western parallel, let us consider the early 17th century curriculum at Cambridge. The leading studies at the time were classics, rhetoric, and divinity; mathematics was slighted and the various sciences practically ignored. During William Harvey's years at Cambridge (1594-1602), the so-called medical course was principally devoted to logic and divinity, rather than "physick." And even as late as about 1630, the university statutes threatened Bachelors and Masters of Arts who failed to follow Aristotle faithfully with a fine of five shillings for every point of divergence from the *Organon*.[54]

However, Bodde noted that a remarkable sea change soon occurred at Cambridge in the mid-1600s, in which the study of mathematics, natural sciences and natural history began to be embraced, paving the way for the Newtonian revolution and ultimately, the Industrial Revolution.

Economic Factors

Needham strongly believed that the lack of economic incentives for merchants and the general failure of medieval era Chinese to establish a healthy capitalist system were key factors that impeded scientific and technological development in modern China.[55]

The economic history of China has largely been shaped by the continuous struggle to feed a large population, while maintaining social order. This goal was the main objective of virtually all its emperors, and remains a primary concern of today's Communist rulers. As more than 70 percent of the country's land mass is either mountainous or arid, China's agricultural policies have long focused on intensive farming of the arable land around the

Yellow and Yangzi Rivers, and the high precipitation regions in the south. [56] Social scientists Kang Chao and Anthony Tang argue that China's large population created a long-term labor surplus, resulting in relatively little need for labor-saving technological innovation given persistent low real wages and sufficient farming productivity.[57] Moreover, excess labor in low-paying agriculture meant that there was little in the way of economic savings to finance capital investment. Without this stimulus, there were few commercial incentives for technological or mechanical innovation.[58] Historian Mark Elvin describes this situation as a "high level equilibrium trap" and suggests that it can answer The Needham Question.[59]

Comprehensive historical evidence, however, demonstrates that the labor argument is flawed. During prolonged periods of labor surplus, such as the 5th to 15th centuries, scientific and technological innovation flourished across China. Moreover, between the 14th and 19th centuries, per capita output of grains more than doubled, while the population quadrupled from 72 million in 1368 to 300 million n 1800.[60] The greatest weakness of the equilibrium trap theory is that it presumes scientific innovation to be the domain of the masses. While peasants in ancient China did produce much notable agricultural innovation, it was the educated classes who should have driven scientific advancement. The equilibrium trap theory is silent on why modern science did not take hold in any demographic.

Needham highlighted the longstanding hostility of the imperial bureaucracy toward the merchant classes as an explanation for his question. From the Han (206BC-220AD) to the Tang (618-907) periods, the state took an almost adversarial view of the merchant class:

> The prime objective of state policy was a settled, stable and contented peasant population, carefully registered and controlled, which would provide regular and ample taxation in kind, and be readily available for labor service or military service when required. In such a society, the merchant was conceived of as a disturbing factor…. Not only was he the advocate of a materialistic attitude…repugnant to the ethical precepts of Confucianism…. He also provided the population with

> a model of a possible means of social advancement based purely on the acquisition of wealth…. Moreover, he was an unstable element in society.[61]

During this period, the government tightly restricted the activities of *shang ren* (merchant businessmen). Commercial activity in large cities was confined to walled marketplaces, where trading hours, the types of goods exchangeable, dealings with foreign parties, transported, distribution and freedom of travel were tightly controlled by local authorities.[62] Most importantly, under the Tang Dynasty, merchants and artisans were excluded from participation in civil service examinations, sending the clear signal that they were not worthy of government service.[63] This ban was not lifted until the Ming period.

However, Needham's anti-merchant argument also has flaws. According to Lin:

> Discrimination against merchants and artisans in ancient China was probably not as serious as Needham makes out…Historical data reveals that successful merchants, money lenders and industrialists of the Han period (206BC to AD8) were treated almost as social equals by vassals, kings and marquises. By the medieval period, big business and financial organizations had already appeared and were flourishing in China, most of them owned by gentry families. Therefore, young men who were not interested in books and learning but who had an adventurous personality could find socially approved outlets in commerce. Furthermore, during the Ming period, the discriminatory laws forbidding merchants to take civil service examinations were formally removed. After 1451, the channel for purchasing offices and even academic degrees was opened. Thus money could be directly translated into position and become one of the determinants of social status.[64]

In Needham's defense, Lin's argument neglects to mention that pre-modern China was not an actively trading society. In external trade, the Ming and early Qing governments virtually closed their doors to foreigners. China's isolationist foreign and economic policies mirrored its Neo-Confucian values. In contrast, western civilization arose around the Mediterranean, which became a natural channel for foreign trade and cultural exchange. The Greek, Roman, Byzantine, Portuguese, Spanish and French empires were all naval powers whose foreign policies were driven by mercantilism

and colonization. Great Britain would follow suit from the 16th century onwards. These powers went to war to secure vital trades routes. Continuous war and economic competition served as vital catalysts to scientific and technological advancement across the European states. Such forces were a non-issue in China, and this fact profoundly impacted its technological evolution.

Politics and Bureaucracy in Pre-Modern China

China's long history differs most distinctly from that of Europe in that the former has, since 221BC, been one unified nation state under centralized bureaucratic rule with a common social philosophy and an essentially homogenous ethnic citizenry. The imperial bureaucracy was central to pre-modern Chinese politics. Some historians argue that this institution played a critical role in undermining the advancement of science and technology. Sinologist Karl Wittfogel, for example, wrote of "hydraulic despotism," hypothesizing that since the Eastern Zhou Dynasty (770BC-221BC), most of the country's economic and planning resources were committed to elaborate hydrological programs. These programs aimed to control the annual flooding of the Yellow and Yangzi rivers.[65] This investment, and the massive bureaucracy built to manage it, effectively crowded out resources that could potentially have been deployed in developing alternative scientific and industrial inventions.[66] Despite having some merit, Wittfogel's theory is far too narrow to explain why modern science did not develop in China despite centuries of such innovation during ancient times.

Soon after consolidating power in 221BC, the Qin Emperor ordered the burning of all books relating to history and the "laws of nature."[67] His motive was to rewrite history and propagate his own political philosophy of "legalism," which was devised to unify the country under an orderly system of laws and regulations.[68] In the ensuing centuries, other rulers conducted similar intellectual purges, especially in the sciences. As Bodde noted, the earliest complete surviving Chinese law code of 653 forbids the private

possession of "all instruments representing celestial bodies."[69] Violators were punishable by two years imprisonment. Bodde argued that government control of astronomy, which continued through the Qing Dynasty, was probably an important reason why science failed to progress beyond a certain point. In 1600, Matteo Ricci, who had been highly regarded by the Chinese literati and high government officials, had to surrender his entire library of European mathematical and astronomical treatises to the Qing court prior to entering the Forbidden City in 1600.[70] He observed that by that time, most Chinese scholars had already lost interest in mathematics and astronomy because of age-old government restrictions.[71]

While the latter theory has some merit, it does not fully address The Needham Question. It is important to compare Europe's own process of scientific advancement at the time to best understand the Chinese situation. From medieval times through the Renaissance, there were also significant impediments in Europe to scientific inquiry and discourse. The Catholic Church over centuries tried directly and indirectly to control the flow of ideas; the most notorious effort in this regard was the Spanish Inquisition. The clash between faith-based dogma and reason came to a head during the Reformation. European men of science such as Copernicus, Galileo and Kepler faced daunting religious, social and political obstacles to free expression and interchange. Despite these barriers to intellectual exploration, the scientific revolution took place in Europe and set the stage for the Enlightenment and Industrial Revolution to follow. Why the same did not occur in China is the key question and accounted for Needham's main intellectual struggle.

Cultural Impediments

Needham stressed Confucianism's role in impeding scientific progress. Confucianism teaches respect for elders and teachers, and admonishes criticism, especially from young to old. It stresses social conformity and does not encourage free thinking. Rote memorization and veneration of the classics are deeply ingrained in Chinese culture. Celebration of antiquity was traditionally preferred to the celebration of scientific advancement or discovery. Zheng He (1371-1433), the great Ming Dynasty admiral, led a fleet of over 200 ships on seven expeditions that reached India, the Arabian peninsula and eastern Africa.[72] His voyages of discovery, however, were hardly recorded in Ming annuls.[73] Zheng He is in fact noteworthy for the reason that he remains a relatively obscure figure in Chinese and world history, unlike Columbus, da Gama, Magellan, Drake and Raleigh. As Bodde observed:

> Reluctance to pursue massive exploration, settlement, trade and exploration abroad also contributed to the lack of scientific development. The voyages of Zheng He to the Indian Ocean and Africa were criticized as wasteful and useless. This contrasts dramatically with the inexorable drive of Europeans, especially from the late 15th century, to explore, colonize and ruthlessly exploit.[74]

Moreover, Confucian philosophy is distinctly anti-violence and anti-war. Never in their history have the Chinese glorified war as a noble undertaking.[75] Therefore, the Chinese people historically felt no need to develop advanced weaponry or major transportation technology—that is, until the foreign incursions of the mid 19th century, when the Qing found themselves hopelessly outclassed in weaponry, logistics and naval strength by the British. Bodde noted that "Confucians had a conviction that a military class does not properly belong to a truly well-ordered state."[76] John King Fairbank wrote more emphatically:

> War is not easy to glorify in the Chinese tradition because ideally it should never have occurred. The moral absolute is all on the side of peace. No economic interest sufficed to glorify warfare; no wealthy neighbors enticed Chinese freebooters across the border or over the sea.... Generals had few triumphs; and they lost their heads as

> often as anyone else. Chinese youth were given no youthful worship of heroism like that in the West…Likewise holy wars are not easy to find in the Chinese imperial records, just as an avenging God and the wrath of Jehovah are far to seek…The whole view of the world is less anthropomorphic and less bellicose than that of the Old Testament, or of Islam.[77]

These observations in particular support Needham's point: Confucian thought combined with anti-war and anti-mercantile philosophies discouraged serious interest in ambitious scientific and technological development. The Chinese government's restrictions on the merchant class during pre-modern times were in part a means of keeping businessmen's power in check; they were also a reflection of the Confucian ethic. Confucian Chinese society was hierarchical and comprised four major classes. In descending order, these where the *shi* (scholars), *nung* (farmers), *kung* (artisans), and *shang* (merchants).[78] In a society where the notion of face" and social status is paramount, the placing of the merchant class at the bottom strata of society is telling. The lowly status of the merchant in China also reinforced Needham's belief that disenfranchisement of this group was a major causal factor in China's failure to embrace scientific and technological innovation. Neither economic incentive nor social respect was accorded to entrepreneurship.

Another cultural response to The Needham Question suggests that imperial China, particularly in the Ming and Qing periods, was simply too arrogant to be curious about innovations and discoveries from the outside world. Lord Macartney, the British envoy who was sent in 1793 by King George III to visit the Qing emperor Qianlong in the hopes of opening up Sino-British trade, was summarily dismissed by the Qing court.[79] The Emperor's letter to the English monarch is revealing:

> As your Ambassador can see for himself, we possess all things. I set no value on objects strange or ingenious, and have no use for your country's manufactures…It behooves you, O King, to respect my sentiments and to display an even greater devotion and loyalty in the future, so that, by perpetual submission to our Throne, you may secure peace and prosperity for your country thereafter.[80]

Since their first encounters with Spanish and Portuguese traders along the southern coast of China in the 15th and 16th centuries, the imperial Chinese looked down on all foreigners as "barbarians." This prejudice also applied to Western inventions and ideas. The Chinese conceived of themselves as the Middle Kingdom between Heaven and Earth; this hubris can explain why they were generally uninterested in embracing foreign science and innovation. However, this pride still cannot fully explain why indigenous modern science did not develop beyond the 15th century, given the preceding centuries of spectacular ingenuity.

Idiosyncrasies of the Chinese Language

Another answer to the Needham paradox suggests that the Chinese written language itself presented a major barrier to the development of modern science. Because Chinese is a pictographic language with no alphabet or universal building block system, it was very difficult to develop movable-type printing. Producing books, manuscripts, journals and any other form of mass printing was therefore time-consuming and expensive. This fact must have presented a great hurdle in the dissemination of scientific ideas, research and methodologies.

Movable-type was invented during the Northern Song Dynasty (1041-1048)[81] Characters were engraved on moistened clay blocks and placed under a categorization system within an iron frame. These clay typesets were later replaced with wood and then bronze. However, the complex nature of Chinese characters made large-scale printing cumbersome. In 1298, it took several months to print 100 copies of the 60,000-character book *Shengde Gazetteer*, entailing the production of 30,000 wooden block characters.[82] In 1319, it took half a year to print a few dozen copies of *The Extended Meaning of The Great Learning*, which utilized over 100,000 wooden block characters.[83] In 1773, the Qing government had 253,000 bronze moveable types made to print 64 sets of *The Collection of Rare Editions at the Hall of Military Eminence*.[84] In contrast, soon after

movable-type printing became available in Europe in the middle of the 15th century, information exchange grew at an astonishing rate as printing presses became more widely available.

But the movable-type theory begs more questions than it resolves. Most obviously, how can it explain the fact that the scientific and industrial revolutions took place in Western Europe and Britain, whereas they did not do so in the Arab, Persian, Greco-Roman and Ottoman worlds, cultures whose languages were also alphabet-based? Moreover, it fails to explain why the Chinese language did not seem to inhibit the development of pre-modern science and technology in China over such a long period of time. Needham himself dismissed the theory:

> There is a commonly received idea that the ideographic language was a powerful inhibitory factor to the development of modern science in China. We believe, however, that this factor is generally grossly overrated. It has proved possible in the course of our work to draw up large glossaries of definable technical terms used in ancient and medieval times for all kinds of things and ideas in science and its applications…We are strongly inclined to believe that if social and economic factors in Chinese society had permitted or facilitated the rise of modern science there as well as in Europe, then already 300 years ago the language would have been made suitable for scientific expression.[85]

The Chinese language is not just a medium for communication and expression. It is, more importantly, the principal carrier of Chinese culture Imbedded within almost every picture-based character is a legacy of history, customs, folklore and philosophical teachings; in essence each word is a story that conveys profound meaning. Much of this meaning is subtle and nuanced. In a way, the Chinese language can be considered an even more sophisticated means of knowledge transmission than any alphabetic or phonetically-based language. Indeed, the scientific wisdom of the ancients was spread around society through this very mechanism, and new characters were invented to convey new concepts, inventions and discoveries.

The Needham Question and the Industrial Revolution

An obvious corollary question to the Needham puzzle, and one which Needham himself pondered, is: Why did the Industrial Revolution originate in Britain, and not in China? This question would appear easier to address than The Needham Question itself. By the middle of the 18th century, the great universities of Britain and Europe had been heirs for over four centuries to the individual, free-thinking rationalism emanating from the Age of Reason, the Renaissance, the Reformation and the Age of Discovery. Britain was in the throes of the Enlightenment. Science was blossoming at universities and academies, and free exchange between scholars and scientists in Britain and the continent was more the norm than the exception.

In addition, the British Patent System of 1624 laid the grounds for the Industrial Revolution in Britain in two ways, according to economic historian and Nobel laureate Douglass North.[86] Firstly, it gave clear incentives to inventors by protecting their intellectual property rights for a defined period of time. Secondly, by making public the key technical processes of each patent, the system provided a legitimate mechanism for technology and knowledge transfer—and its attendant benefits to other would-be inventors within society.

Ultimately, the furthering of economic, commercial and military interests pursuant to Britain's mercantilist and colonization policies of the 16th to 19th centuries were the fundamental drivers of British scientific and technological innovation. These factors were wholly absent in pre-modern China. The Chinese considered such policies repugnant and irrelevant. China simply had no force driving it to an industrial revolution.

Conclusion

Based on the weight of historical evidence, the most persuasive answers to The Needham Question are the influence of Neo-Confucianism and the lack of clear economic incentives for systematic innovation. Neo-Confucianism inhibited the advancement of science in two ways: firstly, in its philosophical teachings; and secondly, in its impact on the imperial civil service examination system. The examination system itself effectively crowded out scientific study and development. By the time China realized the need to develop strategic technologies, the Qing Empire was already crumbling under incursions from more advanced European nations. Gunboat diplomacy, the Opium Wars, their resulting "unequal treaties," humiliating defeats in the Sino-Japanese War and the Boxer Rebellion, and invasion by Japan on the eve of World War II were the consequences of failing to embrace modern science and technology over so many centuries. When finally forced into war and the world marketplace, China suffered for its years of self-sufficient isolation.

How significant was The Needham Question during Needham's lifetime, and how relevant is it today?

The Needham Question attracted keen intellectual interest from academia in the West. Writing at the age of 93, Needham summarized the intellectual importance that he attached to the question:

> If you wish to explain why Europeans were able to do what the Chinese and Indians were not, then you are driven back upon an inescapable dilemma. One of the horns is called pure chance, the other is racicalism however disguised. To attribute the origin of modern science entirely to chance is to declare the bankruptcy of history as a form of enlightenment of the human mind. Racialism, in the political sense, has nothing in common with science. Racialism is neither intellectually respectable nor internationally acceptable. Humankind requires a great revival of interest in the relations of science and society, as well as a study ever more intense of the social structures of all the civilizations, and the delineation of how they differed in glory from one another.[87]

In essence, Needham believed that science and civilization are inextricably linked. In his mind, Ming and Qing society did not consider the advancement of science necessary or important. He felt that value judgments which equated scientific prowess with cultural superiority were spurious to the Chinese. To many westerners, Needham seemed an apologist for China's failure to develop and adopt modern science and technology. Perhaps he was; however, his observations were informed by a deep nuanced appreciation of Chinese thinking and morality.

At the conclusion of his final volume of *SCC*, Needham highlighted the moral importance of his quest: "If a single word was to be sought to describe the guiding thread which has run through all the volumes, I would be inclined to use the word 'justice.' When I started writing, justice was not being done in the West to the other great civilizations."[88]

The Needham paradox also underpins "The Great Divergence" theory put forth by Samuel Huntington in *The Clash of Civilizations and the Remaking of World Order* (1996) and Kenneth Pomeranz in *The Great Divergence: China, Europe, and the Making of the Modern World Economy* (2000). The Great Divergence theory analyzes the reasons why economic growth took off in Europe and the New World in the period following 1600, while by comparison the economies of Qing China, Mughal India and Tokugawa Japan stagnated. Pomeranz argues that the main cause, not surprisingly, was the Industrial Revolution and the fact that modern science and technology were neither encouraged nor embraced by Asian societies during this period. The fact that the Age of Reason, the Renaissance, the Age of Discovery, the Reformation and the Enlightenment took place in Europe also weighs in the calculus. The various theoretical answers to The Needham Question are important contributing factors in this discussion.

It is evident, however, that the conditions present when The Needham Question was first conceived no longer apply in today's China. The influence of Confucianism has been on the wane since 1949. As noted, the Chinese Communist Party (CCP) discouraged adherence to Confucianism in an attempt to replace it with Com-

munist ideology, mainly to maintain their control over society. Perhaps more detrimental to Confucianism has been the post-Mao era focus on economic growth and consumerism. Deng Xiaoping proclaimed in 1992 that "to get rich is glorious," and pushed the country into economic overdrive. Consumerism, materialism and a form of extreme capitalism have replaced Confucianism, Taoism and Buddhism as the ethos of many in China—especially the urban, upwardly mobile younger generation.

"Capitalism with a Chinese face" has taken sway over the country. Since the Deng market reforms of the late 1970s , GDP growth has been the key performance metric for the country's leadership. Entrepreneurship has been embraced, along with technological innovation. Successful businessmen, unlike the merchants of pre-modern China, are the new heroes of the aspiring middle classes. In 2002, the CCP took the unprecedented step of inviting leading capitalists into the party's membership.[89] In today's China, the Confucian social order has been turned upside down. In one of history's great ironies, *shang ren*, the merchant class, now sit close to the apex of society, right alongside the ruling Communist party elite.

Politically, the CCP and central government control society and most of the economy. The Chinese bureaucracy is still large; however, it is no longer defined by meritocratic civil service examinations. Party loyalty is now the main arbiter of appointment and advancement. Moreover, government is generally business friendly, given the emphasis on economic growth. The most important difference between modern and imperial Chinese government is that the civil service today is no longer the principal conduit to social status and wealth. Power still resides in the CCP, but more and more Chinese prefer to find success in the private sector.

As noted, post-Deng Chinese culture has changed radically from that of ancient and imperial China. In fact, it is changing more rapidly than any culture in the history of mankind. While Confucian values appear to remain strong within the family unit, an almost extreme materialism is consuming much of contemporary Chinese society. Needham's observation that there were no

economic incentives encouraging merchants to invest in scientific invention is now quite the opposite. Venture capital, stock markets and fierce domestic and global competition provide tangible incentives for scientific and technological innovation. Entrepreneurs and scientists are responding, and there are a growing number of technology-related success stories coming from China.

Most importantly, the leadership of the CCP and the state are now the domain of scientists and engineers. A remarkable 70 percent of Politburo and State Council members have advanced degrees, of which 62 percent are in natural sciences, applied sciences or engineering.[90] This statistic reflects decades of Soviet-style central planning. The enormous investment in physical infrastructure (highways, bridges, airports, railways, telecommunications and energy—including the massive Three Gorges Project is a testimony to an industrial engineering-based economic model. Government funding for scientific research and development has grown at a compound annual rate of 17 percent over the past decade, and in 2009 was RMB548 billion (or US$88 billion), representing 1.6 percent of GDP.[91] The government is targeting to spend 2.5 percent of GDP on scientific R&D by 2020, implying an annual spending of well over US$250 billion within a decade.[92] The number of students enrolled in higher education has grown from four million in 1999 to more than 19 million today.[93] The most popular university majors are engineering (61 percent) followed by business, finance and accounting (24 percent).[94] The Confucian legacy has indeed been turned upside down.

Given these circumstances, it would appear that China is ripe for scientific discovery and technological innovation. Needham biographer Simon Winchester echoes many contemporary observers of the Chinese economy in his bullish assessment. He argues that China's former scientific stagnation

> ...may be seen in due course as more of a hiatus, more of a hiccup in China's long history, than a permanent condition. Today's China.. has become so rich, energetic, freewheeling, awesome, and spectacular—that the situation which so engaged Joseph Needham and the small army of Sinologist who followed in his footsteps may itself well have come to a natural end.[95]

A closer examination of modern China, however, indicates that we should be cautious about making overly optimistic predictions concerning Chinese scientific innovation. Beneath the veneer of stunning growth and heavy research and development lie several impediments to sustainable technological discovery. Education in China is a politically sensitive area and is tightly controlled by the CCP. The Chinese pre-tertiary education system is still heavily examination and rote learning based. Free, creative and critical thinking are impossible in a culture that emphasizes recitation and regurgitation, often of irrelevant and largely useless information. Many secondary schools and universities have poorly equipped science laboratories, and textbooks are often outdated. Teaching quality is erratic, and observers comment that teaching is poorest in higher education. Confucian values of social conformity and refraining from criticizing teachers and elders remain firmly engrained. There is evidence of widespread plagiarism and academic dishonesty, in part reflecting the lack of intellectual property rights protection.[96] Since 2002, nearly one third of college students have not been able to find satisfactory employment upon graduation, a testimony to the perceived poor quality of higher education.[97] There are restrictions on freedom of speech and expression, which impact freedom of thought and creativity. Moreover, the obsession with money making, consumerism and material success has made Chinese, young and old, more short-term in their thinking. Many businesses act short-term, often preferring speculative gains and "copycatting" to actual long-term investment in human resources and genuine innovation.

These factors are very different from those Needham and other investigators identified with The Needham Question. Nevertheless, they represent similar impediments to scientific and technological advancement in modern China. It may thus be premature to dismiss the Needham paradox as irrelevant.

Of greater importance than the relevance of The Needham Question, however, is the significant of Joseph Needham's life and work itself. On a multitude of levels, his intellectual accomplishments were monumental. At six feet five inches in height, he was

literally a towering figure. His long life spanned all 10 decades of the tumultuous 20th century. He mastered eight languages, three of them ancient. Even his name was epic; he was christened Noel Joseph Terence Montgomery Needham. He is the only person to have concurrently been appointed Fellow of the Royal Society, Fellow of the British Academy and Companion of Honour, three of the greatest accolades bestowed by the British establishment. It is telling that the man who now occupies his former study in Caius College, Cambridge is the renowned physicist Stephen Hawking.

F.W. Sanderson, Needham's headmaster at Oundle School, inspired his students to "always think in a spacious way, think on a grand scale."[98] Needham did not fail his mentor. Professor Mansel Davies wrote in Needham's obituary:

> Intellectually a bridge builder between science, religion and Marxist socialism, and supremely so between East and West, he has been called the Erasmus of the 20th century. A sober assessment suggests that, with the passage of time, he will be recognized as a greater figure than the scholar from Rotterdam.[99]

Kenneth Rexroth, one of Needham's most eloquent critics, wrote of *Science and Civilization in China*:

> Needham's book has the same stunning relevance as Gibbon's *Decline and Fall of the Roman Empire*.…In sheer interest and lucidity, it is the superior of any history of science and related subjects since Heath's great work on Greek mathematics.…There is no work on Chinese civilization in any language that will remotely compare with it, and there are few works which show our own culture at its best, or which raise those best qualities to new heights. Those new heights are reached by forcing us to discard all the baggage of our own conceit.[100]

Philosopher and literary critic George Steiner compared Needham with Proust, and hailed him not only as a remarkable scientist and historian, but also as a gifted artist:

> He is literally recreating, recomposing an ancient China, a China forgotten in some degree by Chinese scholars themselves and all but forgotten by the west. The alchemists and metal workers, the surveyors and court astronomers, the mystics and military engineers of a lost world come to life, through an intensity of recapture, of empathic insight which is the attribute of a great historian, but even more of a great artist.[101]

Needham's former research assistant, Dr. Gregory Blue, comments that "serious and widespread comparative study of the history of science would have been almost impracticable before the appearance of his [Needham's] work, but it is now inevitable."[102] Quoting Sivin, Blue brings attention to the more profound ethical impact of Needham's work: "In the course of broadening and deepening our integral understanding of traditional Chinese culture, practically every paragraph that Needham has written has been designed to be world history, and to urge upon readers a more humane perception of the future."[103]

Perhaps Needham's greatest contribution to humanity was his insistence on studying the history of science in the context of civilization. He saw the two as inextricably linked. He was trained as a scientist, but he lived, thought and wrote as a humanist. Indeed, the title of his magnum opus was purposefully constructed to link science with civilization. More importantly, Needham did not view subject areas as isolated silos, as areas for specialization *per se*. While he meticulously organized *Science and Civilization in China* using conventional taxonomy (mathematics, astronomy, medicine, metallurgy, alchemy, the main engineering disciplines), his genius was to frame these in the cultural context in which ideas, innovations and inventions evolved. His works make us realize that science cannot be fully understood or appreciated through mathematical logic, induction, hypothesis testing and other analytical methods. Needham insisted that science must be learned in the context of culture, language, history, religion, philosophy, and the economic environment—in short, the entire civilization of a people. In fact, he believed that science and technology form an integral part not just of a country's civilization, but also the entire human civilization.

If Needham were alive today, he would no doubt be delighted, and almost certainly not surprised, by China's astonishing economic resurgence. He would have considered the scientific stagnation of the last five centuries as a momentary pause in the timeline of history. However he would likely be dismayed by the relentless pace of modernization, and its toll on Confucian-

Taoist values and the physical environment. Like many traditional Chinese who are ambivalent about China's race into modernity, Needham would surely hope that the Chinese people, lead by an enlightened set of rulers, will somehow find their way back to the Neo-Confucian principles which guided ancient China for over a millennium. Given the perils of climate change, natural resource depletion, rampant pollution, and nuclear and biochemical weaponry, a firm re-rooting in Confucianism and Taoism would be welcomed not only in China, but by all humankind. Respect for nature, and focusing inward on the mind rather than on materialism, is an ethos that kept Chinese civilization stable, unified and harmonious for over 2,000 years. Needham, above all the humanist, offers modern China and the world precious lessons in the responsibilities of science to civilization.

Afterword

I became interested in The Needham Question after reading Simon Winchester's biography of Needham entitled, *The Man Who Loved China* (New York: HarperCollins, 2008). The man's life, times and astonishing intellect were every bit as fascinating as the grand question he posed.

Joseph Needham was born in 1900 in London, the son of an affluent doctor. He graduated from Cambridge with a degree in biochemistry in 1921 and received his Ph.D. in 1925. That year, he married Dorothy Moyle, herself a talented Cambridge scientist. He joined Gonville and Caius College, Cambridge as a biochemistry researcher, and became an authority in embryology and morphogenesis. In 1931, he published the three volume text *Chemical Embryology*, a seminal work documenting the history of embryology from ancient Egypt to the early 19th century.[104] He was elected a Fellow of the Royal Society a decade later, an immense achievement for such a young scientist.

In 1937, he met and fell in love with Lu Gwei-djen, a research associate who had come to Cambridge from Nanjing, China. The

two would have a lifelong affair lasting until her death in 1991. Interestingly, Needham's romantic relationship with Lu was sanctioned by Dorothy Needham, and the three enjoyed an unusually open and cordial friendship. It was Lu who introduced Needham to Chinese culture, civilization and language. She tutored him in classical Chinese and within two years, Needham could read and write at a high level of proficiency. Thus began his lifelong love of China, ancient and modern, scientific and humanistic.

Needham's intellectual and personal life was remarkably colorful, and his energies almost boundless. Besides teaching, researching and writing, he was an avid Morris dancer, a devoted Anglican lay preacher and an avowed nudist. His mastery of Chinese language, history and culture was exceptional for a man who started studying them in his late 30s. He was as eccentric as he was brilliant, and Needham lore abounds. An encounter in Fujian at the height of the Second Sino-Japanese war sheds light on the man's fascinating persona:

> Needham and his party were travelling on horseback with guides through a remote, forested region. Suddenly, they came up against another horseback party on the trail, led by a notorious local bandit, their terrified guides whispered. Needham dismounted, stepping in front of the party, up to the bandit leader's horse, and with his customary vigor executed an English folk dance. The bandit watched with interest. When Needham had finished, the bandit dismounted, stepped forward, and performed one of his own ethnic dances. The ice thus broken, everyone laughed and shook hands, and the two parties proceeded on their respective ways.[105]

At the same time, this Morris-dancing nudist could leave most readers breathless with his titanic intellect and erudition. Below is a not atypical entry from *Science and Civilization in China*:

> The philosophy of history was brilliantly studied in the T'ang period with "The Generalities of History of Liu Chih-Chi" in AD710—the first treatise on historiographical method in any language, quite worthy of comparison with the work of the European pioneers Bodin and de la Popolinire, eight and half centuries later. At that later time, China was also to have her Giambattisto Vico in the person of Chang-Hsueh-Cheng. But it was Liu-Chih-Chi's son Liu Chih (fl. C732) and another T'ang scholar, Ta Yu, who invented a new form of encyclopaedic

> institutional history, the former with his "Governmental Institutes," the latter with the famous "Comprehensive Institutes—a Reservoir of Source Material on Political and Social History," issued in AD801. But the climax to this sort of work was not reached until the Yuan period, when in 1322, "The Comprehensive Study of the History of Civilization" by Ma Tuan-Lin saw the light. His lucid and outstanding treatise in 348 chapters was essentially a general history of institutions…it paralleled the sociological history initiated by Ma's near contemporary, the great Ibn Khaldun, and the history of institutions later to be achieved by Pasquier, Giannone and de Montesquieu.[106]

Also adding color to Needham's profile was his sympathy toward Communism. As early as the Bolshevik Revolution, when Needham was still a teenager, he exhibited an emotional (as opposed to intellectual) attachment to Marxist socialism.[107] At Cambridge, he was an active member of several socialist groups. He supported the Republicans against the Fascists during the Spanish Civil War, and later became enamored with the Communist party movement in wartime China.[108] He was welcomed by Mao Zedong and China's premier Zhou Enlai during the Chinese Civil War and in the decades thereafter.[109]

Equally fascinating was his involvement with UNESCO. Needham lobbied hard to have "science" added as a pillar division to what was originally going to be the United Nations Education and Cultural Organization.[110] In 1946, he was invited by long-time Cambridge friend Julian Huxley, the founding Director-General of UNESCO, to assume the directorship of its sciences division. Needham served happily in Paris for UNESCO until 1948. He had not planned to leave his comfortable and stimulating position in Paris so quickly. He was forced out by pressure from the CIA, who had discovered Needham's history as a longtime Communist sympathizer.

He returned to Cambridge in 1948, where he lived until his death in 1995. He served as Master of Caius College from 1966-1976, and spent the remainder of his working life supervising the colossal *Science and Civilization in China* series.

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Interviews

Dr. Gregory Blue, Professor of History, University of Victoria, Canada and personal assistant to Joseph Needham, 1977-1990

I interviewed Dr. Blue via email exchanges during November and December 2010.

Dr. Peter L. Lee, Honorary Secretary, East Asian History of Science Foundation, Hong Kong

Dr. Lee was a research fellow at Gonville and Caius College Cambridge, 1976-1977, and worked under Joseph Needham. I interviewed Dr. Lee in Hong Kong on 9 December 2010 (on the anniversary of Needham's 110th birthday).

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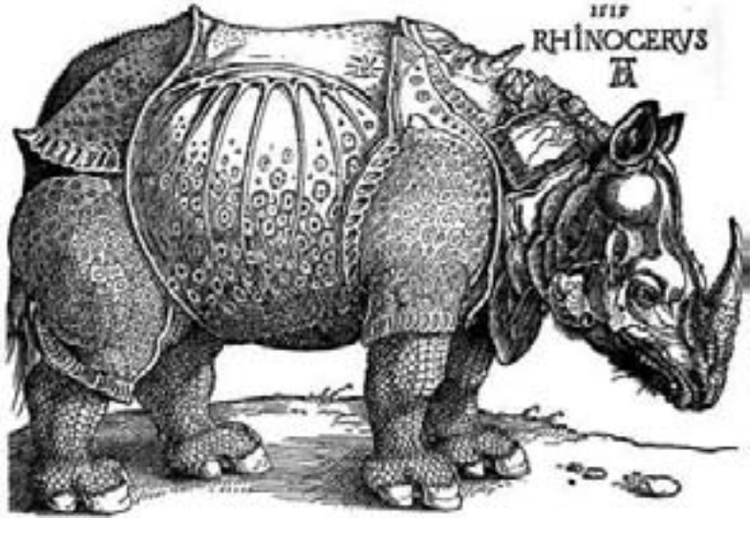

Adrian Goldsworthy

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As Cicero would later declare: "For what is the life of a man, if it is not interwoven with the life of former generations by a sense of history?"