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An Examination of the Needham Question: Why Didn't China Have a Scientific Revolution Considering Its Early Scientific Accomplishments?

Rebecca L. Olerich
The Graduate Center, City University of New York

AN EXAMINATION OF THE NEEDHAM QUESTION: WHY DIDN'T CHINA HAVE A SCIENTIFIC REVOLUTION CONSIDERING ITS EARLY SCIENTIFIC ACCOMPLISHMENTS?

BY

REBECCA OLERICH

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_______________________	_______________________
Date	Joseph W. Dauben
	Thesis Advisor
_______________________	_______________________
Date	Elizabeth Macaulay-Lewis
	Executive Officer

THE CITY UNIVERSITY OF NEW YORK

ABSTRACT

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Advisor: Joseph W. Dauben

Joseph Needham (1900–1995) formulated several important queries about science and technology in China. Known as Needham's "Grand Question" or "Puzzle," he asked why modern science developed in Europe rather than in China, despite China's advanced technology, and examined the inhibiting factors in Chinese civilization that prevented the rise of modern science by the seventeenth century. The question itself has prompted a variety of answers, all of which are partial. In this thesis, some of the complex social, cultural, political and economic factors that contributed to the Scientific Revolution in Europe will be discussed, as well as some of the key historical factors that prevented the development of modern science in China. In particular, I will focus on the imperial examinations in China and will argue that these examinations aided in hindering the development of modern science in China.

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INTRODUCTION

> Modern science is indeed composed of contributions from all the peoples of the Old World, and each contribution has flowed continuously in it, whether from Greek and Roman antiquity, or from the Islamic world or from the cultures of China and India.
>
> —Joseph Needham[1]

By the time Greek philosophy and science permeated the Roman world of the second century C.E., Europe had achieved significant scientific accomplishments crowned by works such as Ptolemy's the *Almagest* and the biological writings and illustrations of Galen—works that would have a profound impact on the natural philosophers of the Renaissance in the first decades of the fifteenth century. As early as the death of Emperor Diocletian in 305 C.E., the political and economic instability of the Roman Empire was irreparable. Intellectual endeavors in the sciences stagnated and the natural world was comprehended largely through mysticism, magic and eventually the forced doctrines of Christianity and the might of the papacy. Only later, with the gradual influx of Greek and Arabic scientific treatises into Europe in the early fourteenth century and the fall of Constantinople in 1453, did Europeans slowly begin to revive old traditions and restore ancient knowledge. In the process, new methods and discoveries were ascertained that both augmented and discredited some of these former ancient scientific works, influencing the development of the scientific and technological advances made during the Scientific Revolution.

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[1] Joseph Needham, "General Conclusions and Reflections," in *Science and Civilisation in China*, Vol 7, part 2, ed. Kenneth Robinson (Cambridge: Cambridge University Press, 2004), 25.

Roughly concurrent with the demise of the Roman Empire, during the reign of the Eastern Jin Dynasty (265–420 C.E.) and the Northern and Southern Dynasties (386–589 C.E.), China had also realized significant scientific and technological achievements which greatly influenced the coming centuries. Even earlier than the first century B.C.E., the Chinese had invented the seismometer, the waterwheel, the wheelbarrow and made advances in metallurgy. A collection of writings on mathematics dating from 186 B.C.E., the *Suan shu shu,* was used as a reference tool for government bureaucrats to determine such things as taxes proportionate to an item's value or the status of an individual's class, official rank, or wealth. Other problems involve the calculation of tolls or how to determine the wastage or amounts lost in casting metals or husking grain. Many of the computations in the *Suan shu shu* involve determining exchanges, especially of grains, in various ratios depending upon differences between grains, their quality, or levels of refinement. Geometry is also considered, with formulas for computing the areas of farmland shapes, i.e. squares, circles, rectangles, or the volumes of such regular solids as wells (cylinders) and haystacks (cones). Several problems concern the largest square that may be cut from a circle of given diameter, or the largest circle that may be cut from a square whose side is known. In short, the *Suan shu shu* was a guide for administrators who needed to be adept at carrying out mathematical computations in a variety of everyday situations. In addition to such applications, the Chinese improved rudimentary approximations of *pi* and even used calculations with negative numbers.[2] Also, astronomers in China detected the supernova in 185 C.E., similarly noted

[2] Joseph W. Dauben, "*Suan Shu Shu*, A Book of Numbers and Computations: English Translation with Commentary," *Archive for History of Exact Sciences*, Vol. 62, no. 2 (March, 2008), 92–94.

by the Roman historian, Cassius Dio.[3] Parallel with the cessation of the Roman Empire, the fall of the Northern and Southern Dynasties, too, ushered in a period of political and economic instability, and Buddhism, having entered China in the later years of the Han dynasty (202 B.C.E.–220 C.E.), began to equal the importance of Confucianism as a cultural force. While both China and Europe remained steeped in societal turmoil, China went on to make three well-known important discoveries: woodblock print and paper, the magnetic compass and gunpowder—all of which facilitated Western Europe's transformation from the Medieval period to the modern world as noted by Francis Bacon in 1620:

> 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.[4]

As these scientific and technological innovations were incorporated into European society, Europeans began to attain hegemony over a vast expanse of the world especially after the discovery of the New World by Christopher Columbus in 1492. Six years later, Vasco da Gama of Portugal navigated the Cape of Good Hope, sailed across the Indian Ocean, developed ports in Kerala and Goa and renewed contact with China on Macao in the South China Sea—ultimately establishing economic trade and beginning the transmission of Western science on a limited scale to China by the Jesuits. In Europe, the old social and intellectual orders were being transformed.

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[3] Michael Loewe, *Everyday Life in Imperial China during the Han Period 202 BC-AD 220* (London: Hacket Publishing, 1968), 69.

[4] Francis Bacon, *Novum Organum*, Liber I, CXXIX., accessed March 13, 2016, http://www.consitution.org/bacon/nov_org.htm.

The new world of the sixteenth century saw a surge of economic energy, the rapid expansion of trade, and the acceleration toward the rise of capitalism. Strict allegiance to the Vatican and its canons were challenged, and the social upheaval that had begun to brew, at least in Germany, was launched when Martin Luther nailed his famous *Ninety-Five Theses of 1517* on the door of Wittenberg's Castle Church, openly contesting many doctrines of the Catholic Church and thus ushering in the Protestant Reformation. Only a few decades later, with the Reformation's emphasis on one's ability to access truth individually without the interference of religious authorities, at least in Protestant countries, the Scientific Revolution began with the first publications of works by Copernicus and Vesalius in 1453.

As many historians and sinologists have noted, by the fourteenth century, China was a highly developed civilization with a prosperous economy, but never attained similar levels in advancements of science and technology as Western Europe had in the sixteenth and seventeenth centuries, considering its earlier scientific accomplishments. Yet, China remained an imperial feudal society and maintained control over its political structures and Confucian principles where no real social or intellectual disruptions occurred to spur change. Thus, China began to fall or "lag behind" Western Europe in the development of modern science.

The concept of China "lagging behind" has led to many comparative analyses between the East and the West regarding the development of science and technology and an array of questions have arisen among scholars about what impeded traditional China from doing what Western Europe had achieved. Why had not China developed a science that theorized and mathematized its technological inventions like Europe? Why did the Chinese not move forward and why did China remain so insular and somewhat opposed to the new science the Jesuits attempted to transfer in the mid-fifteen hundreds? In the early 1930's, an experimental biochemist from Cambridge University, Joseph Needham (1900–905), addressed these questions after meeting three visiting university students from China, who happened to ask, why not China, or why had "modern science originated only in Europe?"[5] For the next fifty years of his life, Needham researched and reformulated this question of why China had never experienced a scientific or industrial revolution as Western Europe had, considering that earlier China had achieved significant advances far exceeding other civilizations. As a result, he published hundreds of papers on the topic, and launched the monumental series, *Science and Civilisation* (*SCC*), an encyclopedic compendium for which he is most known (as of 2015 a total of 27 volumes, and more in progress), which documents China's history of agriculture, medicine, astronomy, mathematics, physics, chemistry, engineering and numerous technological inventions within the context of not only science, but of world civilization. Needham had hoped that his historical research would evolve into a scholarly understanding of how the development of science and technology had emerged so differently in China compared to Western Europe by examining the cultural contexts and settings of each tradition in addition to documenting the history of Chinese science. Needham's lifelong foray into this question, famously known as the "Needham Question," the "Needham Puzzle," or the "Grand Question," speaks to larger issues about not only the development of science in China, but also of culture and the advancement of an industrialized market economy. In response to Needham's queries, numerous scholars, in both the East and the West, have examined his historiography and have added further to the question with commentaries not always in agreement with Needham's

[5] H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry* (Chicago: The University of Chicago Press, 1994), 418.

interpretations. Indeed, many scholars have argued that Needham exaggerated some of China's scientific and technological achievements and the Needham Question itself has prompted a variety of answers—all of which are partial.

The aim of this thesis is to offer an overview of Needham's work about the history of science and technology in China and to elaborate scholarship that examines why modern science developed in Europe rather than China, despite China's advanced technological achievements, and to analyze some of the inhibiting factors in Chinese civilization that prevented the rise of modern science by the seventeenth century. Research will assess some of the complex social, political and economic factors that impeded China's progress toward a Scientific Revolution as well as some of the key factors that led to the development of modern science in Europe. Through examination of Needham's work and the literature surrounding the Grand Question, some of the technological and scientific advancements of both China and Europe will be highlighted.

The first chapter provides an overview of Needham's life, how he formulated his question, and a brief synopsis of the *SCC,* at first written in large part by Needham himself, as well as several other noted sinologists and historians of science and technology who later contributed. In addition, this chapter will reference some of the key concepts in Needham's work. The second chapter will provide an analysis of the reactions and critiques of the Needham Question by some of the most notable scholars in the field. The third chapter analyzes why technology flourished in China, but not science, and will focus particularly on the advent of paper and the printing press both in China and in Europe. The fourth chapter examines some of the cultural factors in China that impeded scientific growth and will concentrate on the imperial examination system.

CHAPTER I

JOSEPH NEEDHAM AND *SCIENCE AND CIVILISATION*

Joseph Needham had already achieved a distinguished career in biochemistry before his exploration of Chinese science and civilization. He began as a graduate student at Cambridge University in 1921 and soon authored numerous publications and scientific papers on embryology and morphogenesis, resulting from experimental work performed in his laboratory. He won international recognition in this field for a three-volume work he first published in 1931, *Chemical Embryology*, which included a history of embryology from Egyptian times to the early nineteenth century, resulting in over 2000 pages and over 7000 references.[6] Needham's ability to incorporate scientific research into a compendium that encompassed an assortment of references covering a vast expanse of history was a precursor to what he was destined to achieve in compiling the *SCC*, initiated in 1954. Under a pseudonym, Henry Holorenshaw, Needham describes how he himself came to the "great divide" in his course of academic study, probably due to the visiting Chinese biochemists he met in the early 1930's at Cambridge. Holorenshaw wrote that it was as if Needham "received from them some kind of liberation for which he has always been looking….it was clear that talking with his Chinese colleagues about their cultural background, the traditions of Chinese language and literature, he found something equal and opposite to all

[6] John Gurdon and Barbara Rodbard, "Biographical Memoir on Joseph Needham (1900–1995)," *International Journal of Development Biology* 44 (2000), 366–367.

that in which he himself had been brought up, and something for that very reason of compelling fascination."[7]

Not knowing specifically how to answer his visiting students' question, Needham immersed himself in Classical Chinese and there began his admiration and respect for China, a country long thought of as backward in the eyes of Western nations. Having developed a competent command of the language, he began to revere China's people, culture and its history. His passion deepened and he sought passage to China, but because of the ensuing conflicts of the Second World War and the Japanese command of nearly one third of the region, all travel to China was suspended by the British government. According to Simon Winchester in his 2008 biography of Needham, the Japanese forces were particularly bent on destroying China's intellectual community and universities. A Chinese professor, LUO Zhongshu, who received letters from colleagues in Chengdu while visiting Oxford, delivered in "unsparing detail," to a group of scholars from both Oxford and Cambridge, the Japanese assault on China's education system.[8] The British Royal Society responded to LUO's plea by appointing Needham the Director of the Sino-British Science Co-operation Office in China, where he was to provide "practical help" in order that Chinese scientists could obtain the needed supplies to continue their research in a variety of scientific and intellectual institutions.[9]

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[7] Henry Holorenshaw (Needham), "The Making of an Honorary Taoist," *Changing Perspectives in the History of Science*. *Essays in Honour of Joseph Needham*, eds. M. Teich, and R. Young (London. Heinemann Educational Books, 1973), 12.

[8] Simon Winchester, *The Man Who Loved China* (New York: Harper Perennial, 2008), 51–59. For this paper, the information regarding Needham's life in Cambridge and in China during the war stem largely from Winchester's biography.

[9] Henry Holorenshaw (Needham), "The Making of an Honorary Taoist," 12.

In 1943, Needham finally entered China for the first time, arriving at Chongqing in Sichuan Province. Here, he encountered the region's neglected field of Chinese science, and decided to devote the rest of his life to the comparative study of Chinese civilization, history of science, technology and medicine—allowing the world access to China's scientific and technological achievements. For four years, Needham travelled extensively throughout war-torn China, traversing miles and regions of terrain where he met hardship, but where he also met numerous Chinese scholars, with some of whom he was later to collaborate. He visited the Mogao Caves, known as the Caves of a Thousand Buddhas, in Dunhuang, Gansu, where the *Diamond Sutra*, known to be the oldest printed book in the world (dating from 868 C.E.), was discovered and purchased from a monk guarding the cave by the archeologist, Sir Aurel Stein, in 1907.[10] Needham collected sufficient amounts of scientific and historical documents—including volumes of the *Gujin Tushu Jicheng,* a comprehensive encyclopedia of Chinese history up until 1725[11]—all of which later provided some of the research he needed to begin formulating the *SCC* series and to further his inquiries into why modern science originated in Europe and not China. Already in 1944, while in Yunan Province, Needham vaguely began penning his thoughts regarding why China "was lagging" behind the West—with the conviction that his question was "one of the greatest problems in the history of civilisation."[12]

Returning from China to Cambridge in 1948, Needham regarded Chinese science as more advanced up until the thirteenth century than science anywhere else in the world. He planned to

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[10] Leo Deuel, *Testaments of Time: The Search for Lost Manuscripts and Records* (New York: Knopf, 1965), 476–7.

[11] Simon Winchester, *The Man Who Loved China*, 176.

[12] H. Floris Cohen, *The Scientific Revolution: A Historical Inquiry*, 418.

write a book of approximately 700 pages on the history of science and technology in China, but, instead, he eventually compiled seven volumes that fused Chinese and European science.[13] In a brief statement to his publishers at Cambridge University, Needham wrote that in addition to innumerable theoretical and psychological factors that inhibited the rise of modern science in China, there were "concrete" geographical, hydrological, social and economic factors which "moulded Asiatic civilisation differently from that of Europe."[14] Throughout the next two decades while working on the *SCC*, Needham addressed his argument more profoundly in order to analyze the social and economic structures in Chinese and European cultures and to clarify points already published in the *SCC*. In 1969, in *The Grand Titration: Science and Society in East and West*, the Grand Question was reformulated as "why [does] modern science, the mathematization of hypotheses about Nature, with all its implications for advanced technology, take its meteoric rise only in the West at the time of Galileo?" and "Why was it that between the second century B.C. and the sixteenth century A.D., East Asian culture was much more efficient than the European West in applying human knowledge of Nature to useful purposes?"[15] Understandably, his queries underwent an evolutionary odyssey considering the vastness of the question and the decades Needham spent trying to unravel this puzzle.

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[13] Robert Finlay, "China, the West, and World History in Joseph Needham's *Science and Civilisation in China*," *Journal of World History*, Vol. 11, no. 2, (Fall, 2000), 278. Professor Finlay received his Ph.D. from the University of Chicago in 1973 and is Professor emeritus of modern European and world history at the University of Arkansas in Fayetteville.

[14] Jonathon D. Spence, "*The Passions of Joseph Needham: The Man Who Loved China: The Fantastic Story of the Eccentric Scientist Who Unlocked the Mysteries of the Middle Kingdom* by Simon Winchester," *New York Review of Books*, 55:13 (August 14, 2008).

[15] Joseph Needham, *The Grand Titration: Science and Society in East and West* (London: George Allen & Unwin LTD, 1969), 16.

The topics he originally envisioned for the *SCC* expanded exponentially due to the wealth of information and research he and fellow-scholars revealed—demanding more volumes. The average length of time spent in bringing a volume to fruition was 3.3 years, not including the preliminary research before the writing of each volume began, with some portions of each volume resulting first in published scientific papers.[16] Needham directly supervised the publication of 17 volumes. The first two, actually written by Needham along with the aid of his research assistant, WANG Ling, "Introductory Orientations" and "History of Scientific Thought," are especially significant volumes because the basic principles of his historiography are made clear with the contention that before the modern era, Chinese civilization was superior to Europe's. Considering China's presumed weakness in developing a modern science, Needham writes, "How did the Chinese succeed…between the 3rd and 13th centuries, a level of scientific knowledge unapproached in the West…in theory and geometrical systemisation…the emergence of technological discoveries and inventions often far in advance…of contemporary Europe, especially up to the 15th century?"[17] Also written by Needham, along with WANG, was Volume 3: *Mathematics and the Sciences of the Heavens and the Earth* and Volume 4, parts 1–3 on physics, mechanical and civil engineering and nautics, which is the most consulted volume in the series. Needham composed parts 2–4 of Volume 5, outlining Chinese alchemy and the beginnings of chemistry in China, including research on physiological alchemy and its contributions to psychology. He is also

[16] Kenneth Robinson, "Editor's Preface," *Science and Civilisation in China*, Vol. 7, part 2, xvii.

[17] Quoted in A. Rupert Hall's article, "Needham on China," *The Economic History Review*, Vol. 21, no. 2 (August, 1968), 373.

credited, in collaboration with HO Ping-Yu, LU Gwei-djen and WANG Ling, for part 7, "The Gunpowder Epic," in addition to part 1 of Volume 6 on medicine.[18]

Currently, the *SCC* is comprised of seven volumes with more than 27 parts as of 2015. The most recent volume, which Needham never saw due to his death in 1995, was written by Georges Métailie and published in 2015. Completed by Kenneth Robinson in 2004, the last, but not the most recent, Volume 7, addresses the social, environmental and political aspects of the Scientific Revolution in Europe, to which Needham had already alluded in Volume I.[19] Robinson attempted to approximate what Needham's summary of the *SCC* would have been and points out Needham's insistence that the *SCC* was an introductory investigation of complex traditions, with only tentative and heuristic explanations. Today, the *SCC* is an ongoing publication and research entity, a project overseen at the Needham Research Institute, a center in Cambridge, England, for the study of the History of East Asian science, technology and medicine. Since the *SCC*'s inception in the 1940's and publication of its first volume in 1954, the compendium has met with a variety of assessments, both negative and positive.

Not expecting any definitive answers, Needham attempted to approach the history of Chinese science through a Chinese lens with the aim of bridging the long-standing divide between China and Europe that existed in the twentieth century. He wrote at a time when much of the West looked down upon China, believing it to be impoverished and backward. As both admirers and critics have pointed out, Needham often delivered broad generalizations with unsupported assertions in order to create a synthesis for understanding what he took to be interactive

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[18] Kenneth Robinson, "Editor's Preface," *Science and Civilisation in China*, Vol. 7, part 2, xviii.
[19] A. Rupert Hall, "Needham on China," 273.

relations between the East and the West. He clearly believed that "the right" intellectual and economic conditions combined when Western Europe was on the brink of the early Renaissance, which in turn created the necessary conditions for early modern science to rise in Western Europe, or according to Needham, achieved "the successful application of mathematical hypothesis to the systematic experimental investigation of natural phenomena."[20] Although he considered the exact connections between social and economic changes occurring in Europe during this period to be elusive, he held that the rise of modern science in Europe transpired "*pari passu* with the Renaissance, the Reformation and the rise of capitalism," where the successful applications of mathematical hypotheses applied to technological inventions induced private enterprise and scholarship solely for monetary gain.[21] In Needham's reference to the Reformation and the rise of capitalism, one is reminded of Robert K. Merton's thesis, *Science, Technology and Society in Seventeenth-Century England,* which correlates the rise of Protestantism and the growth of early experimental science[22]—a thesis similar to Max Weber's regarding the link between the protestant work ethic and the rise of modern capitalism in his *The Protestant Ethic and the Spirit of Capitalism*[23]—both theses with which Needham was familiar. Merton, like Needham, believed that the scientific advances in the seventeenth century occurred because conditions in society were favorable or right, concluding that "the cultural soil of seventeenth-century England was

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[20] Joseph Needham, "Science and Society in East and West*," Science and Society* 28, no. 4 (1964), 386.

[21] Ibid*.,* 387.

[22] Robert K. Merton, "Science, Technology and Society in Seventeenth-Century England," *Osiris*, Vol. 4 (1938).

[23] Max Weber, *The Protestant Ethic and the Spirit of Capitalism* (NY: Dover Publications, 2003).

particularly fertile for the growth and spread of science."[24] For Merton, science was a powerful tool; pursuing activities that were practical and useful glorified God, and "the scientific study of nature tends to enlarge man's dominion over it."[25] Earlier, Weber, in a similar vein, asked what factors enabled European society to transition to a modern society, believing developments in Europe predetermined Europe's step toward modernization with the development of the Protestant work ethic, or the spirit of hard work and the rational pursuit of economic gain, which led to the rise of modern capitalism. Weber believed that a man's calling in life was an exercise in ascetic virtue, and "For if that God, whose hand the Puritan sees in all the occurrence of life, shows one of His elect a chance of profit, he must do it with a purpose. Hence the faithful Christian must follow the call by taking advantage of the opportunity."[26] One's economic mandate is not just to labor, but to labor rationally, with purpose, in realizing one's chosen calling in life.

Although there is certainly an overlap in the perspectives among Merton, Weber and Needham, there are also differences. Most significantly, Needham did not limit his analyses to only the West, but saw science, and its history, in terms of the entire world. He believed that in China, "wealth held no prestige, affluence, or "spiritual power." "It [wealth] could give comfort, but not wisdom" and "the one idea of every merchant's son was to become a scholar, to enter the imperial examination [system] and to rise high in the bureaucracy," not to accumulate more wealth.[27] Needham believed that "perhaps socialism was the spirit of un-dominating justice" al-

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[24] Robert K. Merton, "Science, Technology and Society in Seventeenth-Century England," 597.

[25] Ibid., Robert K. Merton, 431–432.

[26] Max Weber, *The Protestant Ethic and the Spirit of Capitalism*, 161–162.

[27] Joseph Needham, "Science and Society in the East and West," 394.

ready "imprisoned within the shell of Chinese medieval bureaucratism" with traditions "more congruent with the scientific world cooperative commonwealth than those of Europe."[28] He agreed that the development of capitalism and modern science, accompanied by Protestantism, happened only in Europe, but that other important sociological factors must be taken into consideration when examining why China had no scientific revolution, and to "reject the validity or even the relevance of sociological accounts," only illuminates the intellectually unacceptable stance that Europeans embrace "some intrinsic superiority to all other groups of people."[29]

In Needham's 1938 review of Merton's *Science, Technology and Society in Seventeenth-Century England,* he recounts the correlations between Protestantism, capitalism and science, but writes that Merton omitted any mention of the Levellers, a political group during the English Civil War (1642-1651), which promoted common ownership, and which was already "aware of the impact of the coming scientific movement upon social relations."[30] In 1939, under his pseudonym of Henry Holorenshaw, Needham wrote a short historical account of the Levellers in *The Levellers and the English Revolution*, with the preface being written by Needham himself, where he asserted that a communal society was first envisioned in England, linking the Levellers to English socialism and science in the seventeenth century.[31] In as much as Needham championed a societal collective, he similarly viewed science as having socialist elements. The fact that tra-

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[28] Ibid., 394.

[29] Ibid., 407–408.

[30] Joseph Needham, review of "Science, Technology and Society in Seventeenth Century England by Robert K. Merton," *Science & Society*, Vol. 2, no 4 (Fall, 1938), 669–569.

[31] Robert Finlay, "China, the West, and World History in Joseph Needham's *Science and Civilisation in China*," 273.

ditional China did not attach monetary gain to science was attractive to Needham, and this was reflected in his later research. While working as a biochemist, Needham was greatly influenced by Karl Wittfogel, the German Communist Party's foremost expert on China before 1933. Needham viewed Wittfogel as an orthodox Marxist who was interested in further developing the concept of "Asiatic bureaucratism," described by Marx and Engels as the "Asiatic mode of production." Karl Marx, in many of his contributions on China to the *New York Daily Tribune* in the 1850's, wrote about the injustices of British foreign policy and the uprisings from disaffected groups that resulted from the Treaty of Nanjing in 1842 and 1845. Marx saw in these uprisings the possibility of a Chinese revolution throwing a "spark into the overloaded mine of the present industrial system" that would in turn cause political unrest abroad as well.[32] However, what Marx meant by "Asiatic mode of production" is debatable, which Needham acknowledged. All in all, Marx placed China outside the stages of social development in his view of world history, paying little attention to the nature or the traditions of Chinese society as Needham had, and at one point, wrote that China had a "fossil form of social life."[33] Needham, in explaining what he originally admired about Wittfogel's "Asiatic bureacratism," suggested that many of the successful public works throughout the history of China existed because of a centralized Chinese bureaucracy, which superseded some of the negative tribal-like barriers inherent in feudal societies. Needham saw Chinese feudal society as highly bureaucratic, but he did not find fault with this as Wittfogel grew to do, because Needham believed that a well-functioning bureaucracy was indis-

[32] Karl Marx, *Marx on China, 1853-1860: Articles from the "New York Daily Tribune*," ed. Dona Torr (London, 1970), 7.

[33] Quoted in Jonathan D. Spence, *The Search for Modern China*, 1st edition (New York: W.W. Norton & Company, Inc., 1991), 184.

pensable and a "magnificent instrument of human social organization"—something necessary in a society where the use of modern science and technology would surely increase. Needham also pointed out that the bureaucratic feudalism that existed in China was different from European feudalism and accounted for China's "total inhibition of capitalism and modern science" when compared to the West.[34] Notwithstanding, Needham was often criticized and stood out as a Marxist, but was also writing at a time when the West undervalued China because of its Communist system of governance. The United States and Europe were in the throes of the Cold War, when most tenets of Marxist thought were denounced. Unfortunately, after emigrating to the United States during World War II, Wittfogel became a staunch Cold War conservative and one of the harshest critics of Needham, admonishing Needham's view of imperial China's "bureaucratic feudalism" in his review of the second volume of the *SCC*.

According to Needham, China had little economic incentive for scientific development because it lacked a merchant-capitalist system—a system in which traditionally production was under imperial control with no division of labor between industry and agriculture and where theoretically all land was owned by the emperor. China was dominated by a centralized-bureaucratic state whose major functions were the collection of taxes for the imperial court and the administration of public works such as canals and roads, which helped bureaucrats manage the country's topography and agricultural production. Initially, China's feudalism esteemed advances in "natural knowledge and its application to technology for human benefit, while later on it inhibited the rise of modern capitalism and modern science in contrast to the West which favored it."[35] To

[34] Needham "Science and Society in the East and West," 395–396.

[35] Ibid., 388–391.

Needham, a mercantile system could never be fully realized in China because land and industrial enterprises generally could not be inherited and therefore wealth accumulation could not occur. Yet, Needham saw China's medieval economic system as more rational than medieval Europe's. According to Gregory Blue, a former Research Associate at the Needham Research Institute, the *SCC*'s harsh reviewers' perspectives were shaped by the Cold War and their repudiation of Needham's "creative relation to Marxism" was misguided. Blue defends Needham's formulation of "Asian bureaucratic feudalism" as simply a Marxian category. Blue believes that Needham's isolation in Cambridge shielded him from contemporary Soviet and Chinese orthodoxy, and that his understanding of Marxism came prior to the "Stalinist historiographical model" because Needham approached "Marxism with the attitude of an intellectual committed to synthesizing cogent insights from various bodies of thoughts."[36] While Marxism was an integral part of Needham's intellectual development in examining the Grand Question, Blue characterizes Needham's Marxist notions "as being of the heterodox variety" because he distanced himself from orthodox Marxism, claiming Needham a "synthetic thinker who drew selectively on a variety of schools and traditions in pursuit of insight into the subjects that interested him."[37]

Although Needham likened the differences in the development of science between China and Europe to their different social structures, he was also a devout Anglican, who believed in the liturgical elements of the church. Robert Finlay describes Needham's Marxism as a "highly personal amalgam of Marxism and Christianity, embryological models, evolutionary theory, and

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[36] Gregory Blue, "Joseph Needham. Heterodox Marxism and the Social Background to Chinese Science," *Science and Society,* Vol. 62. no. 2 (Summer, 1998), 206.

[37] Ibid., 214.

traditional Chinese philosophy."[38] To Needham, the Anglican church signified the predisposition of evolution and history. Individual cells naturally create organisms, and people naturally create communal institutions:

> All kinds of organisms find their place in such a scheme—insect societies, ecological associations, groups of cells explained in vitro, determined and undermined transplants, polymer molecules, liquid crystals, bombarded and disintegrating atoms, bombed yet still functioning cities, traffic in blood-vessels or arterial highways, sessions of scientific societies, visions of the World Co-operative Commonwealth to come.[39]

Needham considered biological evolution a struggle that endeavored to grow from the most primitive to the highest forms of life and different from the growth order of the low to high in physics or chemistry, which were fields "not yet impenetrable by the human mind or ruled by unintelligible spiritual entities.[40] Translated into terms of Marxist philosophy, Needham interpreted a new dialectical level.

Relating the Neo-Confucians and the Daoists[41] to dialectical materialism, Needham believed the Daosists had already moved toward belief in the unity of dialectical materialism over 1500 years ago with the Neo-Confucians institutionalizing it in the 12th century.[42] Why science developed differently in the East and the West, then, was also due to different philosophical tradi-

[38] Robert Finlay, "China, the West, and World History in Joseph Needham's *Science and Civilisation in China*," 275.

[39] Joseph Needham, *Grand Titration*, 124.

[40] Joseph Needham, *Order and Life* (Cambridge, MA: The M.I.T Press, 1968), 45.

[41] Taosim is the Wade-Giles standard spelling, but Daoism is the Romanized *pinyin* spelling, the current international standard, and will be used throughout this thesis. Similarly, *Dao*, or The Way, will be used rather than *Tao*. Sources in Chinese script are quoted using the original spellings of the author; the *pinyin* spelling will follow in parentheses where necessary.

[42] Robert Finlay, "China, the West, and World History in Joseph Needham's *Science and Civilisation in China*, 300.

tions. Needham found that in China, Buddhism and Confucianism caused an inward-looking conformity that marginalized the significance of studying science and mathematics. The Neo-Confucian school that became prominent in the Song Dynasty (960–1279 C.E.) emphasized social harmony and ethical goodness, enforcing virtues that included the veneration of ancestors and compliance, occluding the development of science—yet, it was also a time when science and technology flowered prodigiously. Chinese society was taught to respect nature, to leave it alone and to accept its consequences because the natural world was too complex to be comprehended—all of which inhibited the development of methods for the investigation of nature. However, Needham also believed that Daoism was associated with early science because Daoism attempts to understand nature from an intuitive and observational perspective and was especially innovative in chemistry and astronomy. The Daoists' emphasis on the feminine "may be regarded as a symbol for the receptive approach to Nature" because "[it] sensed that the scientist must approach Nature in a spirit of humility and adaptability, and not with that masculine ordering sociological determination which the Confucians had."[43] To Needham, the *Dao* was not just The Way or just Nature, but the "Order of Nature" where discovery of natural laws was possible.[44]

In Volume 3 of the *SCC*, Needham wrote that the Chinese lacked the idea of a "creator deity," important to the Newtonian world-view, but instead held the conviction that the universe was self-sufficient, cyclical and organic, leading to the "concept of all-embracing Order in which there was no room for Laws of Nature, and hence few regularities to which it would be profitable

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[43] Joseph Needham, *Grand Titration*, 158–160.

[44] Wing-Tsit CHAN, "Neo-Confuciansism and Chinese Scientific Thought," *Philosophy East and West*, Vol. 6, no. 4 (January, 1957), 312.

to apply mathematics in the mundane sphere."[45] Instead of basing the originality of Chinese mathematics on geometry as is the Western tradition, Needham explained that Chinese mathematics was algebraic even though he was aware that no general theory of equations could have emerged considering traditional mathematics in China was mainly performed on counting boards.[46] Although different from the method the Greeks employed, who often gave justification or proof for their mathematical solutions, LIU Hui, a mathematician from the third century C.E. who wrote commentaries on the *Nine Chapters*, or *Jiuzhang suanshu*, one of the oldest known texts on mathematics written during the Han dynasty, was an exception. LIU Hui offered tenable explanations for the 246 mathematical problems compiled in the *Nine Chapters,* a reference book intended for Han accountants who needed to survey land, calculate distance and length to transport crops, and collect taxes, for example. A large portion of the *Nine Chapters* is based on arithmetic, some geometry and algebra, or linear systems, and even uses negative numbers.[47] In LIU Hui's preface to the *Nine Chapters*, he notes that clear explanations on methods of calculation will ensure that future generations would receive truth, not error, with the "hope of simplicity while remaining complete and general, but not obscure, so that the reader [of the commentary] will be able to grasp more than half" of the calculation methods.[48] Particularly interesting is LIU Hui's explanation on how to prove or dissect problems involving right triangles, which are gen-

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[45] Joseph Needham and WANG Ling, *Science and Civilisation in China*, Vol. 3 (Cambridge, UK: Cambridge University Press, 1959), 153.

[46] Ibid., 150.

[47] Jean-Claude Martzloff, *A History of Chinese Mathematics*, trans. Stephen S. Wilson (Berlin: Springer-Verlag, 1997), 13–14.

[48] Ibid., 69–70.

eral theories comparable to the Pythagorean theorem.[49] During the Song, any mathematical achievements that did take place were closely related to the dynasty's desire to solve practical and social problems pertaining to land management, food storage and distribution, and monetary exchange. Traditional Chinese mathematics was not abstract because the Chinese did not see mathematics in any philosophical sense or as a means to comprehend the universe.[50] When mathematical patterns were established, they "were quite in accord with the tendency towards organic thinking" and equations always "retained their connection with concrete problems, so no general theory could emerge."[51]

Another important theme that appears throughout Needham's *SCC* is the contrast he emphasizes between the Chinese organic conception of the universe and the mechanistic viewpoint that developed during the Scientific Revolution, intermingling his Marxism and his perspective on Chinese philosophy. In sixteenth- and seventeenth-century Europe, the Renaissance holistic belief that the universe was permeated by living matter and subjected to the inclinations of nature, gave way to the belief in a mechanistic framework—composed of inert matter—explained with logic, experimentation and mathematics. Fundamentally, the mechanical philosophy that emerged in early seventeenth-century Europe implied that all qualities could be reduced to mechanical and quantitative properties of size, shape and motion. It assumed that both organic and inorganic substances were determined by mechanical laws of motion that were external to mo-

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[49] Ibid., 297

[50] Joseph Needham, *Science and Civilisation in China*, Vol. 3, 153.

[51] Joseph Needham, "Mathematics and Science in China and the West," *Science and Society*, Vol. 20, no. 4 (Fall, 1956), 323.

tion itself.[52] In Needham's attempt to meld Chinese and Western philosophy, he maintained that the Daoists had already developed an organic conception of nature in the 3rd century B.C.E. as did subsequently the Neo-Confucians in the 12th century C.E. These philosophies were transmitted to Western Europe in reports submitted by the Jesuits and supposedly became rooted in Western philosophy, which the Marxists in the twentieth century recognized as part of their own intellectual traditions. Gottfried Wilhelm Leibniz (1646–1716), writing at a time when Descarte's mechanical philosophy had already become immensely popular in Europe, helped bridge the intellectual gap between China and Western Europe by corresponding with Jesuits in Beijing in an attempt to link the philosophies of Neo-Confucianism and the mechanical philosophers. Leibniz believed that alternate explanations for mechanical philosophy were necessary, distinguishing whether God's existence was admissible in reasoning about how the universe functioned amid the natural sciences or if the processes of life were self-determined and not explicable according to physics and chemistry alone. Needham interpreted Leibniz' correspondence with the Jesuits as an unwitting attempt to liberate Western civilization from its scientific mentality of cultural superiority and technology driven by capitalism—ultimately influencing Marxist doctrine.[53] In essence, Needham believed the development of science in China was organic. Although the Chinese did not produce a Scientific Revolution, modern science in Europe could not have developed without Chinese philosophy:

> The possibility that while the philosophy of fortuitous concourses of atoms, stemming from the society of European mercantile city-states was essential for the construction of modern science in its 19th century form; the philosophy of

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[52] Paolo Rossi, *The Birth of Modern Science*, trans. Cynthia De Nardi Ipsen (Oxford, UK: Wiley-Blackwell Publishers, 2001), 122–125.

[53] Robert Finlay, "China, the West, and World History," 276–278.

> organicism, essential for the construction of modern science in its present and coming form, stemmed from the bureaucratic society of ancient and medieval China…All that our conclusion need be is that Chinese bureaucratism and the organism which sprang from it may turn out to have been as necessary an element in the formation of the perfected worldview of science, as Greek mercantilism and the atomism to which it gave birth.[54]

Wen-yuan QIAN, in *The Great Inertia*, calls Needham's philosophy of organicism "correlativism" because the development of science in China correlated to its development as a civilization.[55] To Needham, in order to understand how science developed differently in China and Europe, not only should social and economic structures be examined, but also systems of ideas. China's organic materialism was illustrated "from the pronouncements of philosophers and scientific thinkers of every epoch. The mechanical view of the world simply did not develop in Chinese thought, and the organicist view in which every phenomena was connected with every other according to a hierarchical order was universal among Chinese thinkers."[56] In Needham's view, the Chinese philosophy of organicism did not prevent the Chinese from developing scientific inventions or achievements in mathematics.

Another significant cultural factor relevant to how Needham addressed his question can be found in his discussion regarding the imperial service examinations for entrance into the culture of the Chinese elite, which he believed initially favored "the growth of natural knowledge and its application to technology for human benefit"—believing that the examinations "brought the best brains of the nation" together, creating an educated society of talented scholars, who

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[54] Quoted in Wen-yuan QIAN, *The Great Inertia: Scientific Stagnation in Traditional China* (London: Croom Helm, 1985), 132.

[55] Ibid., 133.

[56] Joseph Needham, *Grand Titration*, 21.

were "created afresh in every generation…enjoying no hereditary principle of succession" as in the West.[57] Similar to the Daoist philosophy, the imperial examination system originally favored the study of science, but later was thwarted, because Asian "bureaucratic feudalism" was in deep contrast to Europe's form of feudalism where a mercantile order in society eventually rose and furthered incentive for scientific and technological innovations:

> A predominantly mercantile order of society could never arise in Chinese civilization because the basic conception of the mandarin eye was opposed not only to the principles of hereditary aristocratic feudalism but also to the value-systems of the wealthy merchants. Capital accumulation in Chinese society there could indeed be, but the application of it in permanently productive industrial enterprises was constantly inhibited by the scholar-bureaucrats, as indeed was any other social action which might threaten their supremacy.[58]

What Needham meant when he wrote that imperial service examinations initially encouraged the growth of natural knowledge is open to criticism. The examination system first began in the seventh century during the Sui Dynasty (580–618) and included testing in subject areas that included mathematics, astronomy and the "laws of nature," but after centuries of reformulation, the main curriculum of the examinations was the study of classical Confucian texts—leaving little time for the study of the sciences. The study of natural sciences that did exist was *allowed* rather than *encouraged*. What the examination system did achieve was that it allowed the selection of a bureaucracy capable of maintaining imperial China by appointing educated men to "positions of power, something that was not even contemplated under feudalism in Europe."[59] Educated men at the top echelon studied the classics, but civil-scholars on a "lower intellectual plane" such as

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[57] Wen-yuan QIAN, *The Great Inertia*, 197.

[58] Joseph Needham, "Science and Society in East and West," 391.

[59] Joseph Needham, *Science and Civilisation in China*, Vol 7, part 2, 227.

artisans, engineers and astronomers, did study applied science, but it was for bureaucratic purposes largely driven by the necessity of the emperor to link the accuracy of the celestial universe to the livelihood of the people.

According to Needham, the Chinese world-view was entirely different from the Europeans. It entailed "harmonious co-operation of all beings, not from the orders of a superior authority external to themselves," but every part formed a whole "and what they obeyed were the internal dictates of their own natures," where the development of natural laws in a scientific sense were relatively unimportant.[60] To Needham, the Chinese developed practical applications rather than theoretic orientations. With this in mind, it is no wonder that Needham developed the Grand Question. The more he immersed himself in the history of science and technology in China, the more it became apparent to him that the Chinese did have a degree of science. For centuries, they recorded experiments that were repeated with accuracy and measured the celestial skies with acuity as well, but they lacked the necessary attributes to develop modern science like the Europeans had done. Their former achievements remained mostly technological, rather than scientific or theoretical, and they never transitioned toward a scientific revolution.[61]

[60] Joseph Needham, *The Grand Titration*, 36.

[61] Ibid., 62.

CHAPTER II

SOME REACTIONS TO THE NEEDHAM QUESTION

Understandably, any scholar writing on a topic so large in scope is open to criticism with or without an intellectual Marxist impetus. Robert Finlay declared the first volume of the *SCC* in 1954 as "perhaps the greatest single act of historical synthesis and intercultural communication ever attempted by one man."[62] Contemporary historians of science have since paraphrased Needham's original questions, and what scholars contemplate today is why didn't the Chinese beat the Europeans to the Scientific Revolution when considering China's advanced achievements prior to Europe's intellectual emancipation from its medieval ancestors.

Although the Scientific Revolution was significant in shaping the cultural, intellectual and scientific structures of Western contemporary society, several scholars have pointed out that these structures are constructs understood via a Eurocentric lens. Some critics have demonstrated that the Needham Question itself is based on fallacious assumptions and best answered with a refutation. Although LIU Dun, a Professor at the Institute for the History of Natural Science at the Chinese Academy of Sciences, focuses on scholarship about China's "lagging behind," he demonstrates that prior to Needham asking the question, the Grand Question itself was "formed within the context of a firm belief in the inevitability of general human progress, culturally, politically, scientifically and technologically"—a belief dating back to the arrival of the Jesuits in China, who first introduced Chinese civilization to the West since its earlier encounter with Mar-

[62] Quoted in Robert Finlay's article, "China, the West, and World History in Joseph Needham's *Science and Civilisation in China*," 265.

co Polo in the early fourteenth century.[63] He notes that already early on, as the Jesuits attempted to explain why China had neglected to develop science, a Eurocentric understanding of Chinese science and civilization was unwittingly promoted. Quoting the French Jesuit, Domenicus Parrenin from his correspondence with Dortous de Mairan, President of the French Academy of Science in the 1730's, LIU Dun quotes:

> Sir, it would appear inexplicable that although the Chinese had committed themselves to pure theoretical science for a very long period, they had never gone further. I agree with you that the fact is incredible. I do not think it should be imputed to the Chinese mind. If they really lacked for brightness and vigor in questing for knowledge, would their talents and diligence have been exhibited in other disciplines and more than what was requisite in astronomy and geometry? There are many causes entangled together, which have prevented science developing along its expected course, and as long as these causes still exist, movement forward would be blocked.[64]

According to LIU, viewing China's progress in science, or lack thereof, in terms of "inevitable progress" stems from Western scholars bent on identifying inhibiting factors in societies that did not demonstrate progress. He considers the Needham Question as "extending much further beyond the specifics of science in China," believing it is also concerned with how modern and traditional science may coexist. "To find a way of keeping harmony between mankind and nature, science and society, industrial development and a healthy ecological environment, global economic integration and cultural diversity" is key to understanding the differences between the development of China and Europe.[65]

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[63] LIU Dun, "A New Survey of the 'Needham Question'" *Studies in the History of Natural Sciences* 19, no. 4 (2000), 294.

[64] Quoted in LIU Dun, "A New Survey of the 'Needham Question,'" 296.

[65] Ibid., 303.

Similarly, Nathan Sivin, sinologist and Professor Emeritus at the University of Pennsylvania, doubts the validity of Needham asking why science developed in one civilization and not another. He notes that Needham's "question" is a counterfactual hypothesis or a "fallacious assumption" which "happens to be one of the few questions that people often ask in public places about why something didn't happen in history." He also criticizes comparing the entirety of ancient science and technology in one civilization to another because it is too general, and that it is only in contemporary times that science and technology became connected enough to make these comparisons.[66] Needham's posing the counterfactual and analyzing the "problem of the fruitful union of mathematics with science," is an alternative way of asking why the development of science occurred in Europe in the first place and is not a criticism of why China did not develop science.[67] In *On History*, Eric Hobsbawm's view on posing the counterfactual in history supports Needham's claim in the *SCC*'s third volume that in the history of science "the study of an absence can throw bright light upon a presence."[68] According to Hobsbawm, in comparing Chinese and European economics, "Conjectural history has a place in our discipline, even though its chief value is to help us assess the possibilities of present and future, rather than the past, where its place is taken by comparative history; but actual history is what we must explain…The history of society is thus a collaboration between general models of social structure and change and the

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[66] Nathan Sivin, "Why the Scientific Revolution Did Not Take Place in China — Or Didn't It?" *Chinese Science 5* (1982), 5–6.

[67] Joseph Needham and WANG Ling, *Science and Civilisation in China*, Vol. 3, 154.

[68] Ibid.,154.

specific set of phenomena which occurred. This is true whatever the geographical or chronological scale of our enquiries."[69]

Although Sivin's statements are critical on the surface, Sivin, like LIU, gives credence to what Needham as least attempted to illustrate in the *SCC*, which was that achievements in ancient Chinese science and technology were noteworthy, considering the Chinese, as did the Greeks, had their own sense of dualities such as the *yin* and the *yang*, but believed foremost in universal harmony or "the spontaneous cooperation of all the beings in the universe brought about by their following the internal necessities of their own natures."[70] Sivin recognizes that Chinese science prevailed without the dichotomous mind/body, objective/subjective and wave/particle binaries that were systematically applied in the West, which allowed early Western scientists to authenticate a division between the natural physical world and the "province of the soul," where fact and truth were held in high value, but were also not in conflict with religious authorities.[71] The tendency to draw dichotomies between the mind and the body and the subjective and the objective was part of the European mechanistic understanding of the cosmos. To the Chinese in the early seventeenth century, "objective knowledge without wisdom" or "moral or esthetic significance" was base and incomprehensible, and stood in opposition to Confucian philosophy.[72] Sivin does not believe that the early Chinese scientists comprehended what they were doing and concludes that there was not a "systematic connection between all the sciences in

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[69] Eric Hobsbawm, *On History* (New York: The New Press, 1997), 80.

[70] Joseph Needham, *Science and Civilisation in China,* Vol. 2, 412.

[71] Nathan Sivin, "Why the Scientific Revolution Did Not Take Place in China — Or Didn't It?," 7–8.

[72] Ibid., 17.

the minds of people who practiced them" because there was no integration of a natural philosophy, no development of scientific methodology or organization of scientific activity similar to what developed in Western Europe in science academies and universities, which were precursors to a scientific revolution.[73]

Per contra, Sivin argues that China actually did undergo a scientific revolution because of the new science transmitted by Jesuit missionaries, like Matteo Ricci, in the late sixteenth and seventeenth centuries, but that it did not have the same ramifications as the Scientific Revolution did in Europe. In observational astronomy, for example, Chinese scientists learned to apply geometry and trigonometry to define celestial motion by combining some of their own traditional methods with the new science brought by the Jesuits, but without necessarily shedding their traditional values or applying the "mathematization of hypothesis about Nature" to astronomy. One may ask, then, if the Chinese did not "mathematize" their discoveries, how did they experience this scientific revolution that Sivin suggests, especially considering that in the same essay, he emphasizes that the Scientific Revolution in Europe transformed western "knowledge of the external world and changed the questions one asked," how questions were responded to and how ultimately for the first time established "dominion of number and measure over every physical phenomenon."[74] Yet, did the new science brought by the Jesuits help the Chinese transform how they viewed their external world? Did the questions the Chinese asked differ significantly from before the Jesuits began sharing Western knowledge, and did any remarkable societal changes occur in how they viewed or responded to their physical universe? In a critique of the Needham

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[73] Ibid., 4.

[74] Nathan Sivin, *Science in Ancient China* (Aldershot: Variorum, 1995), 16.

Question, Roger Hart, a history professor at the University of Texas at Austin, sheds light on what Sivin argues regarding China having experienced a scientific revolution. To Hart, Sivin "incorporated many of the assumptions within which the class he critiques had been framed" and "by asserting that there was not one but two scientific revolutions," with one in China and one in Europe, Sivin implies that the differences between them "were of degree rather than kind." He adopts the histories of Western science and suggests that the break between ancient and modern science in China was the cause of its scientific revolution, and in doing so, he translates how China and Europe differed when they broke from ancient science, rather than truly noting the specific criteria that was unique to China in forming a scientific revolution except that it did not have the same "transformative powers" as Europe's. Hart views Sivin's attempt to document a scientific revolution in China as "itself a limited copy of the Scientific Revolution in Europe."[75]

Needham wrote that although the science the Jesuits brought was "imperfect," the Chinese understood that this knowledge was "new" rather than Western or Jesuit, and that Chinese astronomy then began its integration into modern science, which Needham considered universal.[76] In *Science in Ancient China*, Sivin discusses the transmission of western mathematics and mathematical astronomy into China as well, calling it a "garbled…transmission that no Chinese could have comprehended." Hart says Sivin's notion that the distorted science brought to China was a means to blame the Jesuits and not the Chinese for their limitations in developing

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75 Roger Hart, "Beyond Science and Civilization: A Post-Needham Critique," *East Asian Science, Technology, and Medicine* 16 (199), 100–101. In Hart's review of Needham, he uses Thomas Kuhn's term, disciplinary matrix, to describe and then dismiss the criteria Sivin uses to claim that China had a scientific revolution. See Thomas Kuhn's postscript to *The Structure of the Scientific Revolution*, 2nd ed., International Encyclopedia of United States series; Vol. 2, no. 2 (Chicago: University of Chicago Press, 1970).

76 Joseph Needham, *SCC* , Vol 3, 442–458.

science.[77] Since the papal Decree of the Congregation of the Index in 1616, the Jesuit missionaries were prohibited by the papacy from discussing heliocentrism until the decree was lifted in 1760. Instead, the Tychonic system was used, which Sivin believed hampered advances in Chinese astronomy. If the Chinese had been given systematic and accurate information, they would have been more than capable of comprehending European modern science according to Sivin.[78] The key to his argument is that even though the Chinese were given distorted information, they were given new tools and new methods to explain astronomy which resulted in what he called a "conceptual revolution in astronomy" because, for the first time, Chinese scholars *believed* that with new mathematical models, phenomena could be explained as well as predicted.[79] This argument is enticing, considering that the Jesuits did bring the Ming court current star maps, the quadrant for measuring the altitude of celestial bodies, the sextant, and the telescope, to name a few.[80] Sivin asserts that Ming encounters with western science encouraged a revival of traditional Chinese astronomy and the rediscovery of ancient mathematics. He also admits that the "only astronomers who could respond to the Jesuits' writings were members of the old intellectual elite," who felt a responsibility to pass these new innovations on to the next generation of students not yet motivated to shed Chinese cultural traditions such as the civil service examinations, because there was no alternative path to security in Ming society.[81] On the surface, Sivin's idea

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[77] Roger Hart, "Beyond Science and Civilization: A Post-Needham Critique," 100.

[78] Nathan Sivin, *Science in Ancient China,* 5–7.

[79] Ibid., 62.

[80] Benjamin A. Elman, *A Cultural History of Modern Science in China* (Cambridge, MA: Harvard University, 2006), 22.

[81] Nathan Sivin, *Science in Ancient China*, 62–63.

that the Chinese experienced a scientific revolution is specious, but he aptly calls this a "conceptual scientific revolution" in astronomy. The Chinese did not accept heliocentrism until much later than Europe did, and the information they were given by the Jesuits was skewed. Sivin notes that revolutions in science, and politics as well, often occur at the margins of society, but that in China, this "revolution" was "attached to the dominant values of their culture," and created the ambition among scholars to "formulate alternatives to conventional ideas" previously relegated to the margins.[82] In essence, China did not experience a scientific revolution like in Europe, and Sivin acknowledges this, but as Chinese scholars became exposed to western ideas after the arrival of the Jesuits, their breakthrough came when they became open to or conceptualized new knowledge, and a revival of their own past mathematical and astronomical traditions reemerged.

Although the Scientific Revolution is often associated with the names of great figures in science such as Copernicus and Galileo, it depended as much on the new academies and organizations that supported the development of science and technology—something Chinese society lacked. The Lincean Academy, founded at the Palazzo Corsini in Rome in 1603, is an example of one of the earliest known science societies whose intentions were to study natural phenomena, attempt new discoveries, teach and publish scientific findings.[83] In 1611, Galileo, already well-known for his publication of the *Starry Messenger* in 1610, attained membership, thus lending his famous name to the academy. In a variety of ways, the early scientific academies in Europe were instrumental in fostering the rise of modern science because they provided an intellectual

[82] Ibid., 64.

[83] Stillman Drake, *Galileo Studies: Personality, Tradition, and Revolution* (Ann Arbor: University of Michigan Press, 1981), 86–88.

space for the discussion of the sciences. At the onset of the Renaissance, the intellectual world in Europe was more immersed in the study of the humanities rather than the study of nature, but this abruptly changed as the Scientific Revolution developed and advanced. In the early seventeenth century, the curriculum at Cambridge University slighted mathematics and focused on classics, rhetoric and religion while faithfully adhering to Aristotelean philosophy and scholasticism. It was only by the mid-1600's that the study of the natural sciences began to be embraced at Cambridge—more than a decade after natural philosophers at Oxford or Gresham College in London, also known as the "invisible college," met informally to discuss scientific observations and experimentation, which was later formalized and called the Royal Society in 1660.[84] Thus, science academies gained influence and prestige as the Scientific Revolution materialized. Natural philosophers began to shed their obedience to the ancients such as Ptolemy and Aristotle, and began to question their theories. Meanwhile, however, the revival of Plato was a source of inspiration for figures like Galileo, and Renaissance Humanists began to put the individual at the center of a new social circle which was quite different from how the individual was viewed in traditional China.

Sinologist, Jonathan D. Spence, differs with both Siven and Needham regarding the transmission of Western science to China. He is convinced that "China did not enter the world of universally valid modern science in any significant way until the twentieth century."[85] Spence finds Needham's concept that science "got through," via the Jesuits, highly suggestive. In his

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[84] Francis R. Johnson, "Gresham College: Precursor of the Royal Society." *Journal of the History of Ideas*, Vol. 1, no. 4 (October, 1940), 425.

[85] Jonathon D. Spence, "The Passions of Joseph Needham. Review of T*he Man Who Loved China: The Fantastic Story of the Eccentric Scientist Who Unlocked the Mysteries of the Middle Kingdom* by Simon Winchester," 181.

research on Matteo Ricci, who entered the Portuguese colony of Macau in 1582, Spence shows that Ricci introduced European science to China, and also recognized the advances the Chinese had made in astronomy in their accurate detection and descriptions of the 1572 supernova and the 1577 comet—alluded to by Ricci in his preface to Euclid's *Elements*, the first six books of which he translated from Clavius' Latin version into Chinese in collaboration with XU Guangqi in 1607. XU was a convert to Christianity and accepted most things Western. Ricci acknowledged that the Chinese were unable to describe their discoveries with any theoretical principles and Euclid's hypotheses were never applied to aid in understanding the observational astronomy already being discussed by intellectuals in China, nor were these hypotheses ever debated or elaborated upon.[86] According to Ricci, Euclid's *Elements* was more admired by the Chinese as a beautiful book on a shelf rather than a tract that was examined or ever put to practical use. To European thinkers in the sixteenth and seventeenth centuries, the *Elements* was a source of inspiration and a guide for the analysis of mathematical and astronomical texts recovered from antiquity. It became the cornerstone of logic for the application of mathematical theory to nature and a rational physical universe. Needham believed China's failure to apply Euclidean geometry or mathematical theory to nature was caused by the dominant Confucian philosophy in that the Chinese did not assume the universe was rationally ordered or that laws could legislate the natural world.[87] Martzloff contends that some translation activities are important when understanding why the the majority of Chinese scholars did not accept Western mathematics even though they had no real compelling reason to reject the *Elements.* He remarks that Chinese scholars may

[86] Jonathan D. Spence, *The Memory Palace of Matteo Ricci* (New York: Viking Penguin Inc., 1984), 145.

[87] Joseph Needham and TSIEN Tsuen-Hsuin, *SCC*, Vol. 5, part 1, 35.

have misunderstood the actual Chinese translation of the *Elements*, *Jihe yuanben*, or "Elementary book on geometry," as merely as a simple book on how to do practical computations, since *jihe* means "how much is that?" and in the *Nine Chapters,* the classic text on Chinese mathematics, every mathematical problem ended with *jihe*, or "how much is that?" Therefore, the *Elements* may not have been considered as a serious text that offered new insight to Chinese literati.[88]

Spence further emphasizes his skepticism about the transmission of European science to China. In illustrating this, he examines the horology section in Volume 6 of the *SCC*, where Needham relates the history of Chinese clockmaking technology, dating back to the Song—a technology seemingly abandoned after clockmaking artisans were forcibly relocated after the Jurchens of the Manchuria-based Jin Dynsasty invaded the Northern Song in 1127 during the Jin-Song Wars.[89] According to Spence, Matteo Ricci encountered difficult politics while stationed in China. To curry favor and gain access to imperial quarters, Ricci strategically introduced the miniature, coil-spring driven clocks developed in Europe in the 1570s and 1580s. Unaware of the earlier Song clockmaking technology, he thought the larger "cog-wheel," sand, and water-driven clocks were all that the Chinese knew.[90] Ricci, believing his miniature clocks of such high-caliber would be desired by Ming officials, attempted to replicate the miniature clocks with both Chinese and European-trained clock craftsman working side by side. Needham interpreted this as the beginning of the development of universal scientific cooperation between the two cultures. Spence says this cooperation was brief because the European clockmaker was dis-

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[88] Jean-Claude Martzloff, *A History of Chinese Mathematics*, 115.

[89] Jonathan D. Spence, *The Memory Palace of Matteo Ricci*, 39.

[90] Ibid., 180.

missed by a Ming prefect whose perception was that the clocks were too difficult to regulate and unnecessary. In premodern China, the imperial ruler monopolized the calendar and managed time for society; governing time was not considered an individual right.[91] To Spence, Chinese and European science never merged, citing horology as a prime example of where the coalescing of eastern and western sciences did not occur. He also notes that the miniature clocks the Jesuits imported to China remained on shelves in the imperial palace, rather than serve as instruments for Chinese thinkers to examine scientifically or replicate —similar to what the imperial Chinese did with Euclid's *Elements*.[92]

Why the Ming prefect never allowed Ricci's clocks circulation, may also relate to the different philosophies of time perception between China and Europe. Stanley Jaki, a philosophy and theology professor at Seton Hall University, wrote that modern science is a unique result of a Hebraic-Christian linear view of time. In non-Hebraic-Christian cultures, science existed, but the "belief in an eternal, cyclic recurrence of everything in a universe which was taken as the ultimate realty…implies a cosmic treadmill and casts the spell of pessimistic hopelessness," inhibiting the quest for scientific principles.[93] In Needham's essay, "Time and History in China and the West," he also argues that the European, or Christian, conception of time and history stems from the Hebraic tradition which depicted world-epiphanies as markers of time with a beginning and end. Christianity, whose roots lay in Israel, formed a "linear redemptive time-process" with

[91] David S. Landes, "Why Europe and the West? Why Not China?," *Journal of Economic Perspectives*, Vol. 2, no. 20 (Spring, 2006), 12.

[92] Ibid., 181–84.

[93] Stanley L. Jaki, "The History of Science and the Idea of an Oscillating Universe," *Cosmology, History and Theology*, ed. Wolfgang Yourgrau and Allen P. Breck (New York: Plenum Press, 1977), 247.

God as the “comptroller of time,” and a faith tied to a future as well as a past.[94] According to Needham, this history-time consciousness contributed to the rise of modern science and technology in Europe. Early astronomers and mathematicians needed accurate time instruments to determine speed, essential for astronomical observations and applications. At the same time, he acknowledged that the Chinese perception of time was originally cyclical, especially among early Daoist philosophers, but believed that a sense of linear time was dominant later among Confucian scholars who aided the emperor in maintaining the *Dao* in order to perpetuate the rhythms of seasonal agriculture or the cycles of nature, which sustained social order and virtuous conduct. The historical tradition of China sought to preserve an idealistic communal past. Randomness or the reoccurrence of social evil or evil dynasties was not cyclical, and if time for the Chinese “had not been linear it is hardly conceivable that they would have worked with such historical-mindedness and bee-like industry…and the theories of social evolution, technological ages…and the growth of human science pure and applied, are in no way missing from Chinese culture.” [95]

Thus, if China did not develop science as the West had, it had nothing to do with their concept of time. The Chinese calendar was based on a 60-year cycle and handed down by the Yellow Emperor, one of the legendary kings from “a golden age” in China, an idealized period of virtuous conduct and rule where Chinese society was at its greatest with social harmony prevailing, the ideal state upon which Confucius elaborated. Attaining progress was to look back at the

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[94] Joseph Needham, “Time and History in China and the West,” *Leonardo* 10, no. 3 (Summer, 1977), 233.

[95] Ibid., 234–235.

golden past and to replicate what had been previously done with no expectations of a future.[96] Sivin believes ancient China lacked the idea of cosmic progress, but came later to realize that changes in nature were rhythmic as every organism, including man and dynasties, and passed through a cycle each with its own *Dao*. It was the emperor's responsibility to provide an accurate calendar which showed the motion of the Moon, Sun and planets—or a regularity—and it was also the emperor's function to manage society so that the *Dao* was not violated—a "matter of state security to understand just what the rhythms were." Since everything passed through cycles from birth to death and all cycles were harmonized with nature, the calendar was essential in explaining celestial cycles and to integrate them into cycles representing the natural world which governed agriculture and the state's bureaucracy. As Sivin has pointed out, the theory of the natural order and the political order were resonating systems. The failure of officials to predict celestial events was a sign of moral imperfection, or an indication that a ruler's virtue was not adequate enough to be in touch with the celestial rhythms.[97] Astronomers and mathematicians, or specially appointed literati, determined these celestial events and the flow of time, eventually using sundials and water clocks as well, but since every moment had its own unique *Dao*, the concept of linear time was balanced with the revolutions of the Sun and the Moon, and theoretical accounts of how the measurement of time worked were considered irrelevant.[98]

H. Floris Cohen elaborates on the Needham Question and scrutinizes Needham's detailed cataloging of Chinese science, finding some of Needham's conclusions misleading and lacking

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[96] Peter Young, "The Sociology of Time: Histories and the Historians in the Cultures of the West and China," *Leonardo* 9, no. 3 (Summer, 1976), 207.

[97] Nathan Sivin, *Science in Ancient China*, 7–8.

[98] Ibid., 86–88.

evidence. While admiring his curiosity regarding the history of Chinese science and its cultural roots, Cohen writes that Needham's insistence on proving that science is universal with the conviction that "mankind is one great family" connotes a Western attitude and not one that is viewed through a Chinese lens, as Needham advocated.[99] In analyzing some of the Chinese scientific discoveries Needham described in the *SCC*, Cohen, like Spence, is skeptical that the science of horology transmitted to China was a reflection of scholarly collaboration. While working in China, Needham uncovered Chinese texts dating back to the eleventh century that detailed large clocks driven by water—and thought to historically predate the invention of the western mechanical Huygen's pendulum clock. Needham recounts a description of an armillary sphere and clock tower designed by the official and astronomer, SU Sung (1020–1101), which was over 30 feet high and showed the position of the stars conducive to correcting previous astronomical observations. According to Needham, SU Sung's hydro-mechanical clock was positioned on a self-contained escapement with a chain-driven mechanism, and "in imitation of the actual heavens," showing the changing locations of the planets and the stars, depicting the phases of the Moon and the days of the month, all perpetually in motion.[100]

In Needham's desire to fuse Eastern and Western science, he maintained that SU Sung's "hydro-mechanical clock thus bridges the gap between the clepsydra and the weight or spring-driven clock" and that knowledge regarding Su Sung's clock was transmitted via India and the

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[99] H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry,* 426.

[100] Joseph Needham, WANG Ling, and Derek J. de Solla Price, *Heavenly Clockwork: The Great Astronomical Clocks of Medieval China*, 2nd ed. (Cambridge, UK: Cambridge University Press, 1986), 114.

Islamic world sometime after 1200 C.E., to Europe.[101] Cohen contends there is no data which proves this cross-cultural transmission of the workings of the water clock, finding Needham's criterion in the *Grand Titration* that cross-cultural transmission is "natural" or that the burden of proof rests on those who wish to deny transmission, as Needham maintained, unsatisfactory:

> As in all other fields of science and technology the onus of proof lies upon those who wish to maintain fully independent invention, and the longer the period elapsing between the successive appearances of a discovery or invention in two or more cultures concerned, the heavier the general onus is.[102]

Quoting David Landes from his *Revolution in Time*, Cohen sketches an alternative to Needham's theory that the water clock in China was the "missing link" back to the Greek clepsydra and that it did not presuppose European mechanical clocks. To Landes, it is this very absence of source data which suggests that Chinese and European clockworks developed independently of one another, with the European mechanical clock being superior. Both Chinese and European clocks employed similar degrees of accuracy in measuring time according to the clepsydra principles, but the Chinese water clock had many destabilizing factors such as changes in the viscosity of fluid due to changes in temperature, i.e., water freezes, and particles from soil cause corrosion that may also interfere with the operation of the clock. Cohen speculates that the disappearance of the clock-work technology and the study of horology after the fall of the Northern Song in 1127 was possibly a result of the imprecision of the water clock.[103] Needham maintained Jin dynasty artisans eventually reassembled SU Sung's clock, but that it fell into disrepair after about 30 years. Needham sites no evidence regarding the purpose for reassembling the clock nor its

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101 Ibid., 190–192.

102 H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry,* 435–436.

103 Ibid., 437.

precision, but suspected it was due to Mongolian barbarity and their lack of technological and scientific sophistication that the clock lost importance.[104] However, after Khublai Khan stabilized the empire, the astronomical sciences again flourished and GUO Shoujing (1231–1316), an official who oversaw the Calendrical Affairs department, built a jackwork clock and celestial globe modeled on SU Sung's design, later examined by Ricci and determined to be as "good a clock as any" known in Europe. When the Ming dynasty came to power in 1368, Chinese clockwork ended and Chinese scholars could not explain their horology to the newly arriving Jesuits—at least according to Needham.[105] In as much that Needham wanted to connect the knowledge of the Chinese water-clocks to the clocks built in Europe, he does not sufficiently discuss why the Chinese never scaled down their clocks or why an armillary sphere was necessary in the first place. If telling time and predicting celestial positions was the private job of the emperor in order to manage the empire, why was the Chinese water-clock so very large and public?

Like Sivin, sinologist A.C. Graham faults Needham's methodology in his attempt to answer a question about something that did not happen and considers the question "two sides of the same coin only if we think of the event as having a single cause which is both necessary and significant."[106] Instead, historians might ask the question from a positive stance which is "why did

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[104] Joseph Needham, WANG Ling, and Derek J. de Solla Price, *Heavenly Clockwork: The Great Astronomical Clocks of Medieval China,* 134.

[105] Ibid., 138–140.

[106] A.C. Graham, "China, Europe, and the Origins of Modern Science: Needham's *The Grand Titration*," *Chinese Science: Explorations of an Ancient Tradition*, eds. Shigeru Nakayama and Nathan Sivin (Cambridge, MA: MIT Press, 1973), 183.

the Scientific Revolution happen in Europe" and why did it happen around 1600?[107] Graham considers the notion of scientific stagnation in China illusory and that scholars should ponder how and why China developed as it did since scientific development in China "was slow only in relation to the accelerating development of Europe since the Renaissance."[108] China's failure to attain modern science is merely proof that China did not follow the same route as Europe. In other words, how does one prove that the conditions which prompted the Scientific Revolution in Europe did not exist in China? Graham contends that no one factor existed in the European pre-modern era, but that interrelated events such as the "meeting of Greek logic and geometry with Indian numerals and algebra, capitalism, the Christian sense of linear time and of a cosmic legislator" inspired the mathematization of hypotheses and controlled experiments which led to modern science.[109] To further his point, Graham reproves one of Needham's social arguments in the *Grand Titration* regarding the absence of a sincere merchant class in China, since according to Needham, the "scholar-gentry and the bureaucratic feudal system always effectively prevented the rise to power or seizure of the State by the merchant class" —thus, inhibiting scientific innovation, unlike in Europe, where the merchant class was democratic and powerful.[110] Graham concludes that the rise of a merchant class would be essential for the rise of science somewhere outside of Europe only if there were necessary conditions in that society that only the merchant class could fulfill. Are these conditions implicit in the connections between the rise of capital-

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[107] Quoted in H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry,* 472–3.

[108] A.C. Graham, "China, Europe, and the Origins of Modern Science: Needham's *The Grand Titration*," 50.

[109] Ibid., 184.

[110] Ibid., 185.

ism? Graham writes that it is necessary to stick to the "historical situation" of a locale or it becomes less and less clear to surmise what could be fulfilled by the merchant class, believing that the conditions favorable for scientific advancement have little to do with whether or not the merchant class wielded any power.[111]

Physicist and Chinese historian, Wen-yuan QIAN, attacks the paradox of the Needham Question in his book, *The Great Inertia*, and asserts that Needham summarized everything "that smacked of science in Chinese history" in order to correct Western misconceptions about China, while encompassing too little of Chinese history. Even though Needham posed his question under the guise of what were the inhibiting factors in China, one theme flowing throughout the *SCC* is that Needham did not utilize words like "inert" or "stagnant" to describe China's scientific history, but instead viewed its history as self-regulative or characterized by "dynastic cycles" that consistently rose and declined, always returning to its original character of institutional and ideological continuity after internal and political disturbances. At the same time, QIAN believes this self-regulative continuity is what justifies applying terms such as "lagging behind" or "inert" to describe Chinese history because it promoted the non-development of not only modern science, but also the non-development of a modern economy or politics. He identifies two ailments dominant in China, one being the philosophy inherent in Confucianism, which was predominantly political and ethical, promoting social and intellectual state control. Over the centuries, this ideology was perfected and consolidated, becoming the central dogma of Chinese bureaucracy. In effect, the ideology institutionalized what QIAN considers to be one of the greatest differences between scientific developments in the East and the West. Unlike Europe, China was imperially

[111] Ibid., 186.

unified which guaranteed the continuation of ideological control and intolerance of continuous intellectual scientific advancements. Any changes in the bureaucratic institution itself were prohibited and the ability for the growth of capitalism and a pluralistic culture were hindered —both of which could have provided incentives for advancements in science and technology. Public disputes and competition were forbidden in imperial China due to its domination by one ideological system and absolute power. In Europe, competition existed between church and state and between states. The culture of competitiveness in Europe rendered resistance or intolerance to new intellectual developments less effective.[112] Second, QIAN links the imperial service examinations, originally dating back to the Sui Dynasty in the late sixth century, to an educational system that allowed the Chinese bureaucracy to maintain state control. Until the beginning of the Song Dynasty in 960 C.E., Needham believed that the imperial examinations brought all of the great minds of China together, no matter one's position in society, where the study of mathematics and science was encouraged. QIAN aptly recognizes that China had long been innovative in developing mechanical skills and technologies, but as of 1313 during the Yuan dynasty (1271–1368), the required reading of all aspiring intellectuals was still narrowly limited to the Neo-Confucian texts, suppressing the intellectual creativity needed to create the theoretical and methodological frameworks of modern science.[113]

In a similar vein, Justin Yifu LIN, an economic historian and former Senior Vice President of the World Bank, argues that the answer to the Needham Question lies in the nature of China's bureaucratic system. Citing Needham's statement that pre-Song culture was initially fa-

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[112] Wen-yuan QIAN, *The Great Inertia: Scientific Stagnation in Traditional China,* 19–23.

[113] Ibid., 91.

vorable to the growth of science, LIN argues that because China lacked feudalism or an aristocracy like in Europe, mercantilistic values never emerged. Any fusion of new scientific and mathematical theories to pre-existing knowledge or technology could not occur. To LIN, China's failure to make the transition from premodern science to a scientific revolution was also due to China's sociopolitical system, not because the system stymied intellectual creativity as both Needham and QIAN argue, but because there was little incentive in the system to propel intellectuals toward scientific endeavors. In premodern times, scientific discovery was often spontaneous and "made by geniuses with innate acumen for observing nature." These genius-like members of European society helped systematize hypotheses and engage in collaboration where scientific knowledge was routinely accumulated. LIN says this accumulation of knowledge gave scientists "a stock of acquired human capital to observe nature in order to determine what could be added to science by empirical observation and experiments." Human capital is necessary for progress, but "the gifted in China had fewer incentives than their Western contemporaries to acquire either new knowledge or human capital."[114] Bureaucratic control and the rigidity of the imperial service examinations also helped impede the accumulation of new knowledge, and in effect, human capital. The imperial examinations allowed the Chinese government to demand strict adherence to its central ideology, since examination questions reflected strictly imposed ideology. Gaining entrance into the Chinese bureaucracy was considered the most prestigious accomplishment one could make in China. Passing the examinations was considered a significant achievement—necessary for social mobility. It provided incentives for society to accumulate the

[114] Justin Yifu LIN, "The Needham Puzzle: Why the Industrial Revolution Did Not Originate in China," *Economic Development and Cultural Change*, Vol. 43, no. 2 (January, 1995), 284.

human capital required for passing the examinations, but not the accumulation of human capital essential for the advancement of modern science.

Jonathan LU, a professor at the Chinese International School in Hong Kong, also agrees that the unified nature of the state bureaucracy in China impeded the development of science, in part, because of the civil service examinations. Preparation required nearly twenty years, or more, of study and memorization —ruling out the possibility of accruing knowledge in the sciences or mathematics. LU notes that originally the system proved favorable for the study of subject areas in mathematics, astronomy and the "laws of nature," which Needham also alluded to in the *Grand Titration*. According to LU, around 220 B.C.E., Emperor QIN established the bureaucratic system of governance that remained largely intact until the overthrow of the Qing Dynasty in 1911. Emperor QIN abolished the hereditary system of government appointments and replaced it with the "recommendation system," in hopes that men of talent would fill government positions rather than relatives. What ensued during the Qin dynasty (221–206 B.C.E), however, was corruption by the wealthy who could purchase government positions for their families.[115] During the Sui dynasty (580–618), and to what Needham may have been referring to in the *Grand Titration*, the government appointment system was reformed with officials again being selected on the basis of intellectual talent and merit. In effect, these reforms ushered in a wider range of topics on the exams, including the sciences. But, by 1313, intellectual progress began to decline because of dynastic political turmoil, eliminating mathematics and astronomy as examination subjects, further enforcing Confucian ideology.

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[115] Jonathan LU, "Reassessing the Needham Question: What Forces Impeded the Development of Modern Science in China after the 15th Century," *The Concord Review* 43, no. 2 (2011), 219–220.

Chapter III

TECHNOLOGICAL FACTORS:
THE PRINTING PRESS IN CHINA AND EUROPE

> The prerequisites for a useful invention include both the physical and mental readiness for the event, beside a creative mind and a popular demand, proper materials and the essential basic techniques must be available.[116]

Although the Chinese did not develop modern science as early as the Europeans did, its history of scientific thinking and technological innovations are much older than Europe's—at least until the fifteenth century. In China, paper making was developed as early as the second century, and woodblock printing six centuries later—much earlier than when Europe adopted its own form of printing. The Needham Question, or what impeded China from developing empirical science by applying mathematical hypotheses or experimental methods to nature, can also be applied to the history of printing and moveable type printing, with the latter often wrongly attributed to the West beginning with Gutenberg in 1440. Professor of Chinese Literature at the University of Chicago, T. H. TSIEN, in collaboration with Needham, addresses China's history of paper making, wood and movable-type printing in the fifth volume of the *SCC*. Taking a comparative stance, they ask why these inventions occurred in China so much earlier than in Europe, considering the physical materials needed for paper, woodblock and moveable type printing were available on both continents. What factors contributed to these developments in China,

[116] Joseph Needham and TSIEN Tsuen-Hsuin, *SCC,* Vol 5, part 1, 3.

and why was there such a delay in Europe?   What were the cultural and social factors that affected the development of paper and printing in both societies? Also, one may ask whether the printing press in Europe aided in the development of the Scientific Revolution? Does this add any insight into answering the Needham Question itself of why modern science first developed in Europe and not in China?

TSIEN's and Needham's historical research details the development of paper and its early widespread use and the advent of woodblock and movable-type printing in China. Although printing could occur on silk and cloth generally, paper eventually became a prerequisite for movable type printing and understanding its eventual transmission to the West in the late seventh- or the early eighth-centuries is worthy of note. Considering the great amount of trade and contact between the Arabs and the Chinese during this period, it is thought that paper was originally transmitted from Eastern Turkestan via the Silk Road to Samarkand where hemp and flax were in abundance, enabling paper's manufacture. From there, the paper industry spread to Baghdad and Damascus via Constantinople, and eventually was imported to Europe. Around 1150, Spain adopted paper making—most likely because it was under Arabian rule. Another possible transmission route was from Egypt to Morocco, and then to Sicily. In central Italy, the first known paper making workshop was in Monte Fano, where hemp paper was produced, replacing the use of parchment, in 1276.[117]

In China, the actual invention of paper is still considered controversial. Originally, it was thought that paper was accidentally discovered during the Eastern Han Dynasty by CAI Lun, a Han official, around 120 C.E., who developed a form of paper using bark, hemp, rags and used

[117] Ibid., 296–299.

fishing nets—later known as Cai Hou paper and highly regarded by the emperor. According to HAN Qi, a leading authority on the history of printing in China, there were already doubts among scholars as early as the Tang Dynasty (618–906) that CAI Lun was the first to develop paper with the thought that he had only made improvements on a product that had previously existed since archeologists in the twentieth century discovered ancient papers from the Western Han Dynasty thought to predate CAI Lun. Yet, shortly after the advent of the CAI Lun paper, paper began to be used for documents and letters, in part, because it was less expensive compared to silk. During the late Eastern Han Dynasty, paper technology improved and expanded, and was officially the standard writing material used in the palace as per the order of the Eastern Jin Emperor, HUAN Xuan (369–404 C.E.). During this period, paper making spread to most regions in the north and south of China.[118]

In the Sui and Tang Dynasties, the demand for paper increased and the use of bark paper became more common. Finely chopped mulberry bark was added to the rag pulp. It, too, underwent continuous modifications and the methods for its production were constantly improved upon. [119] Not only was paper more cost effective than silk, it was also easier to manage and transport than bamboo or wood tablets as a medium, becoming an important commodity. Paper was not only used for collating Confucian and Daoist texts and other books, it was also used for government documents, calendars, ornamental stationery, household decorations, rubbings for

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[118] Jialu FAN *et al.*, *The History of Chinese Science and Technology*, Vol. 2 (Shanghai: Shanghai Jiao Tong University Press, 2015), 170–173.

[119] Joseph Needham and TSIEN Tsuen-Hsuin, *SCC.* Vol 5, part 1, 360.

making stone inscriptions, money, effigies, clothing, painting and calligraphy, kites, lanterns, umbrellas and even toilet paper.[120]

In Europe, on the other hand, demand for paper did not occur until the spread of printing, although it was gradually used throughout the fourteenth century for manuscripts, household records and sundry decorative imports even though papyrus was still abundant, less expensive and more durable than paper. Parchment and vellum, although more expensive, were also more durable and had smoother surfaces upon which to transpose script. Preceding Needham, Carter Goodrich, who also wrote about the history of paper making and printing in China, details the earliest extant paper document in Europe—a deed written in both Latin and Arabic script dated from 1109 by the Sicilian King Roger, who banned the use of paper for official uses because of its fragility. In 1221, Emperor Frederick II also forbade the use of paper for official documents for similar reasons.[121] Needham adds that clergymen, such as the abbot of Cluny in France, verbally attacked the use of paper for official documents, or any commodities from the Arab world because "Europeans were distrustful of anything from a hostile land during and after the Crusades."[122]

The emergence of woodblock printing in China and exact dates for its inception are controversial as well. Literary evidence suggests that woodblock printing may have surfaced as early as the Tang Dynasty in the sixth century because of technical terminology found in historical documents used to describe methods of cutting, engraving, imprinting and publishing, but trans-

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[120] Ibid., 45.

[121] Carter Goodrich, *The Invention of Printing in China and Its Spread Westward*, 2nd ed. (New York: The Ronald Press Company,1955), 137.

[122] Joseph Needham and TSIEN Tsuen-Hsuin, *SCC,* Vol 5, part 1, 5, 163.

lation of the terminology is open to interpretation. Needham ascertains, however, that by the early eighth century, woodblock printing was a method widely utilized in China, in part, because of two specimens found in Buddhist temples in Korea and Japan, the *Dharani sutra* and the *Lotus sutra*. The scrolls of the *sutras* bear particular Chinese characters in use when the Empress WU was ruling China from 690 to 705. Pilgrimages by Chinese monks to Korea and Japan were frequent and it is likely that these documents were printed in China and then transported to both countries. There was great enthusiasm for publishing sacred texts in China. Buddhism teaches that producing large quantities of the *sutras* is a way to receive extra blessings. Mentioned earlier, the first known extant woodblock printed book is the *Diamond Sutra* from 868, discovered by Sir Aurel Stein.[123] There is more evidence, however, of woodblock printing than Needham cites. In addition to both *sutras* mentioned above, which are believed to have been printed earlier than the eighth century, wood block printing shops were widespread and quite developed, and existed in Xi'an (Chang'an), the capital, and also Luoyang (Loyang), the eastern capital, Yuezhou (Yue Zhou Cun), Jiangdong (Jiang dong qu), and Jiangxi, with numerous bookshops appearing in Xi'an (Chang'an).[124]

By the time of the Song Dynasty, woodblock printing was already an advanced technique, the scope of printing had widened, spread across the Chinese border and moved westward. Philosophical and religious tracts were published, including nearly an entire reprinting of the ancestral Buddhist canon called the *Tripitaka*. The golden age of Chinese printing was during the Song era, and "books printed at this time equal[ed] in importance the incunabula produced in Eu-

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[123] Ibid., 149–151.

[124] J. FAN *et al*., *The History of Chinese Science and Technology*, Vol. I, 197.

rope three or four centuries later."[125] In addition, along with works in literature and history, both private printing houses and imperial government presses prospered by publishing extensive medical commentaries, as well as scientific and technological writings. Local government officials, including the Military, Tea and Salt, Judicial and Transportation Commissions, engraved official documents and other books for profit. Private individuals, schools, and temples printed books for commerce. Bookstores and classics' workshops mushroomed. Engraved copies replaced manual copies, offering ease to the reader and inspiring the development of a literary culture.

Justin Yifi LIN, similar to Needham, calls the Song era, which signified rapid, social, cultural and political changes where intellectual endeavors were fostered, "the most cosmopolitan, technologically advanced and economically powerful civilization in the world."[126] Politically, power moved toward a bureaucratic government led by scholar-officials, who gained officialdom by passing the newly reformed civil service examinations, rather than entry by military or aristocratic access. As will be discussed in the next chapter, the civil service examination system reshaped educational settings and the need for printed textbooks and examination materials systematically increased. WANG Anshi (1021–1086), a local government official, helped modify examination questions that existed since the Tang Dynasty, advocating political officials receive less traditional, but more practical training in ancient and modern laws and regulations, along with principles of astronomy and political economy, in order to initiate needed reforms in the dynasty. Diverse subjects of study flourished throughout the three centuries of the Song reign. Comprehensive monographs of the natural sciences were printed on flowers, insects, geography,

[125] Joseph Needham and TSIEN Tsuen-Hsuin, *SCC,* Vol. 5, part 1, 159.

[126] Justin Yifi LIN, "The Needham Puzzle: Why the Industrial Revolution Did Not Originate in China," 270.

and medicine, to name a few. Mathematics accelerated and numerous editions on arithmetic were published, including reprints of the *Chou Pei Suan Ching (Zhoubi suanjing), or the Arithmetical Classic of the Zhou Gnomon and the Circular Paths of Heaven,* from the first century.[127] CHIN Chiu-Shao (QIN Jiusaho), in 1247, was the first to implement the zero symbol into Chinese mathematics where before, blank spaces were used instead of zeros in the system of counting rods.[128] Needham states that the mathematician, GUO Shoujing, used spherical trigonometry in his calculations to improve the calendar system and Chinese astronomy.[129] All in all, commercial printing expanded and the availability of diverse types of printed books accelerated, especially during the Southern Song (1127–1279). Intellectual communities were continually formed, and vigorous academic exchanges among scholar-officials, teachers and civil service examinees flourished, eventually leading to Learning the Way or *Daoxue,*[130] a movement that stressed scholarship rather than action, and the attainment of true introspection regarding civic duty, nature, family relationships and morality. These social and cultural changes during the Song era may not have occurred without the proliferation of woodblock printing.[131] Comparatively, the Song Dynasty was similar to Renaissance Europe in terms of socio-cultural change, when movable type printing was developed by Gutenberg and printed materials spread rapidly.

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[127] Joseph Needham and TSIEN Tsuen-Hsuin, *SCC,* Vol. 5, part 1, 163.

[128] Carrington L. Goodrich, *A Short History of the Chinese People*, 3rd ed. (New York: Harper Torchbooks: The University Library,1963), 153–158.

[129] Joseph Needham and WANG Ling, *SCC,* Vol. 3, 153.

[130] *Daoxue*, which literally means “Study of the Dao,” i.e. Daoism, or Taoism (*pinyin*), refers to Learning the Way or Studying The Way, and these expressions will be used hereafter.

[131] Seung-Hwan MUN, “Printing Press without copyright: a historical analysis of printing and publishing in Song, China,” *Chinese Journal of Communication* 6, no. 1 (2013), 3.

Another remarkable development during the Song era was the advent of movable type printing, invented by BI Sheng (990–1051), whom Needham describes as a commoner. SHEN Kuo (SHEN Quo) (1031–1095), known as a polymathic statesman during the Song, is a good example of a civilian who benefited from WANG An-Shi's modifications of the imperial examinations. SHEN Kuo entered the imperial bureaucracy, not because his lineage was from one of the ancient clans, which was the usual road to attaining administrative positions during the former Tang Dynasty, but because he passed the imperial service examinations in the highest category. He is known for having composed many commentaries on a variety of topics, but is most notable for a piece called the *Dream Brook* (or *Pool*) *of Essays*.[132] One of the most famous accounts of BI Sheng's invention of moveable-type printing is recounted by Needham:

> BI Sheng took sticky clay and cut in it characters as thin as the edge of a coin. Each character formed, as it were, a single type. He baked them in the fire to make them hard. He had previously prepared an iron plate and he had covered his plate with a mixture of pine resin, wax, and paper ashes. When he wished to print, he took an iron frame and set it on the iron plate. In this he placed the types, set close together. When the frame was full, the whole made one solid block of type. He then placed it near the fire to warm it. When the paste [at the back] was slightly melted, he took a smooth board and pressed it over the surface, so that the block of type became as even as a whetstone. If one were to print only two or three copies, this method would be neither simple nor easy. But for printing hundreds or thousands of copies, it was marvelously quick. As a rule he kept two forms going. While the impression was being made from the one form, the type was being put in place on the other. When the printing of the one form was finished, the other was then ready. In this way the two forms alternated and the printing was done with great rapidity.[133]

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[132] Nathan Sivin, *Science in Ancient China*, 27.

[133] Joseph Needham and TSIEN Tsuen-Hsuin, *SCC,* Vol. 5, part 1, 202.

Unfortunately, BI Sheng's invention remained obscure although there were some experimental editions produced using earthenware type and also wood for the next three centuries. In 1313, during the Yuan, WANG Zhen, a magistrate, wrote a brief account of movable-type printing using wood engravings. The incentive for his account was because he wished to have his book on agriculture, the *Nong Shu,* printed using movable type, but it was never realized as printers had already begun to carve blocks for the book.[134] Both Goodrich and Needham note the achievement of WANG Zhen's account, written approximately twenty years after Marco Polo had returned to Venice. Goodrich says this achievement is significant due to two main factors: "The production of type of such a form that they could be made to fit together in a perfectly even and rigid block, and such systemization and mechanical arrangement of the symbols of the script as to make typesetting possible. The achievement of these two things make the invention described here an epoch-making step forward in the history of printing."[135]

Moreover, the methods used by Chinese printers differed from European printers regarding the type of mold used, alphabet type and the press itself. Until the onset of modern typography in the nineteenth century, woodblock printing was the preferred method in China and more suitable to the Chinese writing system where "written words were revered and books were assiduously studied in order to achieve prominence in society."[136] Needham asks why movable type was not used more widely since it had been developed in the eleventh century. His main premise was due to the nature of Chinese ideographic script, composed of thousands of ideograms,

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[134] Carter Goodrich, *The Invention of Printing in China and Its Spread Westward*, 216.

[135] Ibid., 217.

[136] TSIEN Tsuen-Hsuin, *Collected Writings on Chinese Culture* (Hong Kong: The Chinese University Press, 2011), 155.

“which are needed in any extensive writing, since several types are needed for each character, and for the commoner ones twenty or more, a font of at least 200,000 Chinese types is not unusual.”[137] Alphabetical languages require only a hundred or so different symbols, so movable-type printing in China was not practical if just a few copies were needed, which was the pattern of supply and demand, yet economically feasible for large printings. Although ideographic script may have been an impediment for movable-type printing until technical features were improved upon in the nineteenth century, Needham did not believe that ideographic script itself hindered the development of modern science or a scientific revolution in China, rejecting this claim because the contemporary Chinese language, using a similar ideographic script today, has been able to assimilate scientific concepts and technical terms, and develop complex interpretations of the natural world.[138] In other words, how Chinese characters were formed or written did not negatively influence the development of scientific thought.

Yet, another way to examine the Needham Question is by looking at whether language-specific structures in the Chinese language, rather than the script itself, influenced how Chinese speakers communicated and interpreted specific cognitive schema. Needham did write in the *SCC* that Chinese science lacked the logical rigor needed for modern science to develop, and various scholars have speculated that Chinese linguistic structures influence how logic is formulated and is different from how logic is assessed in Indo-European languages.[139] Alfred Bloom, an

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[137] Joseph Needham and TSIEN Tsuen-Hsuin, *SCC,* Vol 5, part 1, 220.

[138] H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry,* 457.

[139] Benjamin A. Elman, review of *The Linguistic Shaping of Thought: A Study in the Impact of Language on Thinking in China and the West* by Alfred Bloom, *The Journal of Asian Studies*, Vol. 42, no. 3 (May, 1983), 612.

American psychologist and linguist, in a study comparing Chinese speaking and English speaking college student's counterfactual responses on a survey, concluded that the Chinese language structure does affect cognition and conceptualization primarily because it lacks the subjunctive mode, unlike Latin and most western languages. In the survey, Chinese speakers were unable to "shift into a counterfactual realm" and even considered counterfactual questions non-Chinese.[140] In applying Bloom's results to the Needham Question, one can argue that the abstract reasoning necessary for the development of modern western science was not easily accommodated by the Chinese language.

Considering the complexities of ideographic script, the use of woodblocks was more convenient than movable type printing for a variety of reasons. Woodblocks were more easily preserved and reused in subsequent generations which efficiently saved labor and material costs, not to mention time. According to Needham, the initial costs of setting movable type were unfavorable compared to woodblock printing. Workers who engraved woodblock were plentiful and inexpensive. The process of carving and rubbing woodblocks was labor intensive, little training was involved and literacy skills were not necessary, with both women and children often employed throughout the industry, whereas movable type required literacy and linguistic knowledge. Therefore, there was little incentive to disturb a well-developed process that was already established.[141]

Another important function of woodblock printing was that it could be virtually free of textual errors if the engravings were controlled by the state. With so many woodblock printings,

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[140] Alfred H. Bloom, *The Linguistic Shaping of Thought: A Study in the Impact of Language on Thinking in China and the West* (Hillsdale, NJ: Lawrence Erlbaum Associates, Inc., 1981), 16.

[141] Joseph Needham and TSIEN Tsuen-Hsuin, *SCC,* Vol. 5, part 1, 221.

errors and shoddy workmanship did ensue, especially during the Southern Song where the publishing industry was most prevalent. In the Masha Township of Fujian Province, books printed were called "masha editions" and known as shoddy and designed for quick sales, becoming synonymous for errors and inferior quality.[142] As long as the first carvings were error free, they were highly valued for texts pertaining to the civil service examinations. During the Five Dynasties period, Emperor MING Tsung (926–933 C.E.), in an edict authorizing the engravings of the *Nine Confucian Classics*, declared that alternative editions were strictly prohibited. This helped strengthen the control of the examination system by the Song government and increased the significance of official publishing, creating more demand for exam-related printed materials which constituted the largest segments of printing.[143] In addition to the difficulties of setting ideographic script, another reason may be that movable type could not be stored like woodblock, and type often had to be reset and regrouped, which was prone to error. The durability of woodblock prints allowed engravings to be reused when the demand for a text rose, eliminating the risk of unsold copies and frozen invested capital if mass-produced. This also allowed the government to control what was being printed for adherence to the standards of the state. Although there were many positive aspects regarding the use of woodblocks, printing large quantities of material was more difficult because of the amount of time it took, and transporting the blocks was cumbersome because of their bulk, making it burdensome to reprint copies of texts outside of the do-

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[142] Jialu FAN *et al*., *History of Chinese Science and Technology*, Vol. 2, 199–201.

[143] Seung-Hwan MUN, "Printing Press without copyright: a historical analysis of printing and publishing in Song, China," 5.

main where the original woodblock was crafted, so the dissemination of texts via block printing was more limited.[144]

The invention of paper can be traced from China to Europe, but how printing was transmitted to Europe has not been fully established. Goodrich suggests that the history of playing cards may aid in the understanding of woodblock printing's westward movement from China. Playing cards most likely developed in China around the same time as printed books developed, replacing Chinese manuscript rolls. Cards, originally called "sheet dice," appeared at the end of the Tang Dynasty, and were probably the earliest form of block printing. Evidence also suggests that playing cards may have been the result of Europe's first woodblock printing. The earliest references to playing cards in Europe are in the 1300's after the Crusades. One assumes that playing cards were transmitted via the Arab world like paper, but there is little evidence in Arabic literature to support this. Games of chance were prohibited according to Islamic religious laws, as was most woodblock printing, because the Arabs thought boar bristles were used in the rubbing and cleaning of woodblock engravings.[145] Both Goodrich and Needham agree that playing cards spread over the Asian continent via Mongol soldiers and traders and were in wide demand in Europe where cards, too, were often prohibited on moral and economic grounds by the church and government authorities.[146] Interestingly, the period when playing cards appeared in Europe coincides with the appearance of religious pictures printed on cards. The Jesuit missionaries in China used religious pictures to aid in teaching the scriptures because they were easy to circulate.

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[144] Ibid., 7–8.

[145] Carter Goodrich, *The Invention of Printing in China and Its Spread Westward,* 183–185.

[146] Joseph Needham and TSIEN Tsuen-Hsuin, *SCC,* Vol. 5, part 1, 309–310.

Needham suggests that both religious images and playing cards were printed by Gutenberg using copper engravings to offset costs in his Mainz workshop slightly before his movable type was invented.[147]

It is clear that woodblock printing originated in China, but whether the origins of typography were developed independently in Europe and whether Europeans had knowledge of moveable metal type from China, are obscure. What is evident, however, is that the invention of moveable type printing significantly impacted Europe, not only socially, but also academically —directly influencing the Scientific Revolution. According to historian Elizabeth Eisenstein, Gutenberg's invention of movable type printing revolutionized Europe and brought radical changes to a society immersed in an evolving intellectual climate already ripe for fomenting modern empirical science. According to Eisenstein, "I think the advent of printing ought to be featured more prominently by historians of science when they set the stage for the downfall of Ptolemaic astronomy, Galenic anatomy, or Aristotelian physics."[148] In China, beginning with the Song, since new technology made printing cheaper, private scholarship and a literate public grew. Collecting and borrowing books became an established custom with some private collections containing over 30,000 volumes. Local schools and academies established libraries, mainly containing printed editions of Confucian classics, histories, literary collections, philosophical works, and some books on Buddhism and Daoism.[149] With more books available, a passion for

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[147] Ibid., 311.

[148] Elizabeth Eisenstein, *The Printing Revolution in Early Modern Europe* (New York, NY: Cambridge University Press, 1983), 109.

[149] Thomas H. C. LEE, *Education in Traditional China, a History* (Leiden: E. J. Brill, 2000), 421–423.

reading continued, and during the Ming dynasty, was no longer monopolized only by scholars, but also an increasing literate population. Although the love of books continued to flourish, private scholarship slowly diminished, and academies and libraries were placed under government control and the public no longer had the same access to books it wanted to read. Instead, books the state thought the public should read were printed in order to control ideology and manage its economy and borders after years of Mongol rule.[150] Thus, printing became an instrument of the bureaucracy, strengthening the state and the civil service examination system, and placing Confucian scholar-officials in central leadership roles. As Needham suggested, printing in Europe helped create social upheaval and stimulate intellectual change especially in the sciences, whereas in China, the printing press was not enough to stimulate the same intellectual diversity in science.

Until the rise of printing in Europe, modern scientific thought was still in its early stages of development. The predominant scholasticism of the period was espoused through mysticism and church dogmatism, but the comprehension of the natural world was beginning to evolve. Already by the twelfth century, urban centers and trade grew as did cathedral schools, universities and increased contact with Arab intellectuals residing in Europe, who introduced Aristotelian treatises and other scientific and philosophical works. Sociologist and historian T. E. Huff says the new cultural institutions that emerged in the early Renaissance "allowed a modicum of space…within which the merits of the new system could be debated without personal danger to those who defended it."[151] To intellectuals of this age, the past was considered the key to

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[150] Ibid., 419.

[151] T.E. Huff, *The Rise of Early Modern Science: Islam, China and the West*, 2nd ed. (New York: Cambridge University Press, 2003), 327.

progress and the ancients were held in high esteem. As the quest for ancient manuscripts grew, intellectual discourse in the fifteenth and sixteenth centuries was dominated by the retranslations of Greek and Arabic texts into Latin and various vernacular languages. Discerning which newly discovered manuscripts most closely approximated the originals was fertile ground for analysis and debate among scholars. For example, the *Iliad* was originally attributed to the authorship of Pindar and it was thought that Homer and Virgil were contemporaries even though they lived centuries apart. Intellectuals were cognizant of the fact that manuscripts such as Cicero's *De oratore,* found in a German monastery, contained considerable transcription variations compared to a copy of the *De oratore* found in a monastery in Italy. By 1500, nearly all Latin classical literature as we know it today, was already transmitted and compiled into first printed editions.[152] As a result, intellectuals were inspired to reconstruct the histories of manuscripts in order to authenticate accuracy and correct errors, providing a more relaxed framework for textual analysis and scholarly interpretation of biblical scripture and Aristotelean knowledge, but also analysis and interpretation of Greek scientific figures such as Galen and Ptolemy. Intellectuals shared a spirit of freedom and were motivated to reclaim past knowledge, a liberty which Anneliese Maier describes as a precursor to laying "bare the principles which make possible a direct knowledge and understanding of nature—a knowledge that is individual, empirical, and independent of all authority."[153] Commenting on this sentiment, H. Floris Cohen, however, contends that these pioneering thinkers continued to be constrained by the main tenets of Aristotelian natural philoso-

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[152] Bolgar, R.R. *The Classical Heritage and Its Beneficiaries* (Cambridge, UK: Cambridge University Press, 1958), 78.

[153] Quoted in H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry,* 266.

phy, preventing 14th-century natural philosophers from gravitating toward real modern science.[154]

One way this constrained manner of thinking was overcome is directly linked, in my view, to the advent of movable type printing by Gutenberg in 1440, which allowed for the printing and proliferation of manuscripts from antiquity, but also promoted the awareness of embedded textual inaccuracies that were passed on to succeeding generations as noted above. Humanist scholars admitted to the enormous value of ancient texts, but suspected that the texts and their commentaries had been eroded by copyists over time. Galen commanded scholarly jurisdiction over anatomy as did Ptolemy over astronomy and Aristotle over physics. By the time of Copernicus and Vesalius, printed books were disseminated widely among academics, but were also available for the general public's perusal in order for printing houses to increase profit, unwittingly allowing lay-persons to educate themselves and study the natural sciences. Printing changed the nature of scholarship by initiating a shift in the demographics of the reading public. Non-academics engaged in reviewing the works of ancient mathematicians and natural scientists. Treatises on scientific topics multiplied after 1500, which not only preserved learning, but promoted novel learning, helping pave the way for unconventional science that differed from the mainstream science taught at universities, authoritative in the Renaissance. Niccolò Tartaglia, who lacked a university education, published new ideas on mechanics and published *Nova Scientia* in Italian, dedicated to a military commander in order to instruct soldiers to use mathematics to perfect their success in the use of projectiles. He also translated a vernacular version of Euclid in 1543, adding commentaries of his own, exposing Italian readers to mathematics and practical

[154] Ibid., 267.

applications of mechanics. In the same year, his edition of the works of *Archimedes* was published. A private pupil of Tartaglia, Ostilio Ricci, was one of Galileo's mathematics teachers — but not connected to a university. On the whole, the relationship between printed texts and scientific studies grew. A new period was emerging which sought to rectify and unify science —a direct result of the printed book.[155]

While the printing press did not necessarily *cause* the Scientific Revolution in Europe, it certainly helped contribute to it and should be taken into account. It helped standardize knowledge and encouraged individual thought at a time when individualism was still equated with arrogance and in violation of papal doctrine. Both Copernicus and Vesalius represent this emerging individualism of thought by questioning knowledge in their respective disciplines. In *De Revolutionizes orbium coelestium*, Copernicus put forth his own theory of heliocentrism, challenging Ptolemy's second-century geocentric model accepted by the Church. Eisenstein notes that Copernicus was able to do what many of his predecessors were unable to do, which was to scrutinize and compare various editions of the *Almagest*, recognizing the errors in translations and textual transmissions between earlier manuscripts, not to mention the errors in Ptolemy's planetary theory. Though Copernicus used his own knowledge and data to justify heliocentrism, Copernicus' new model stemmed from his reading a copy of Aristarchus from the third century B.C.E. referenced by Plutarch. Likewise, Kepler was able to compare multiple theories as a result of the availability of printed ancient texts: "By the time Kepler was a student at Tübingen, astronomers had to choose between three different theories. A century earlier, when Copernicus

[155] Stillman Drake, "Early Science and the Printed Book: The Spread of Science beyond the Universities," *Renaissance and Reformation / Renaissance et Réforme* 6, no. 3 (1970), 51.

was at Cracow, students were fortunate to gain access to one."[156] In addition to contrasting the achievements of the ancients, Kepler drew on contemporary authors such as Tycho Brahe to support his views that went against the traditional views of Ptolemy, and the Copernican account as well. Kepler's second major publication, the *Astronomia Nova* (1609), illustrates that Tycho's observational errors of Mars' distance from the Sun could be corrected with mathematics after numerous calculation attempts, presenting a proof that Mars' orbit is elliptical and not circular, eventually leading to his Third Law of planetary motion, comparing the movement of planets, which influenced Newton's law of the inverse square for gravitation.[157] By not only examining ancient and contemporary texts available due to printing, Kepler endeavored new empirical observation and utilized mathematics, which was especially important for the Scientific Revolution because it brought about accuracy regarding the study of science and these details were recorded and disseminated in his published works.

Similarly, in the early 1500's, anatomical studies among professors were intensively reconsidered, which was aided by the abundance of printed material. "A great rush of anatomical works" ensued, representing the "new anatomy," which challenged the corpus of Galen, unfathomable without the advent of print culture.[158] Vesalius illustrated a new book of anatomy, *De humani corporis fabrica,* contesting Galen's well-known error-ridden anatomical illustrations then in circulation. Not only did he scrutinize Galen's anatomical illustrations, he also initiated

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[156] Elizabeth Eisenstein, *The Printing Press as an Agent of Change,* Vol 2 (New York: Cambridge University Press, 1979), 629–630.

[157] Curtis Wilson, "Kepler's Derivation of the Elliptical Path," *Isis*, Vol. 59, no 1 (Spring, 1968), 5–7.

[158] Maria Boas, *The Scientific Renaissance* (New York: Harper & Brothers, 1962), 142–143.

his own personal observations by performing dissections using cadavers for demonstration and experimentation rather than animal dissections, which were what Galen had primarily used. In Eisenstein's view, it was not Renaissance humanism and the revival of the ancients that propelled the "new anatomy," it was the transmission of methods that had been transformed due to printing—allowing a "'great boost' which led researchers to surpass the ancients and move toward new frontiers for the first time," preventing the harmful duplication of "inherited technical literature" that had been corrupted.[159]

The printing press allowed a uniformity in printed texts and an increase in realistic illustrations with newly collected information. Not only did Vesalius accomplish this, but so did natural philosophers such as Otto Brunfels, a German botanist, who helped extend the ancient surveys of the plant and animal worlds originally provided by Aristotle, Theophrastus, Pliny and Dioscorides. New species were introduced to the European mindset from the Americas, unknown to the ancients, and new illustrations were integrated into the European scientific canon. Precisely identifying new illustrations of species according to the ancients was difficult and improvements on illustrations of herbals and bestiaries by medieval scribes soon became common place. Printed matter permitted comparisons of overly decorative reproductions, inviting personal insights and experiences that were more reliable and empirical, formalizing the associations of plants and animals between the old and the new worlds, and pragmatically confronting the symbolic or biblical significance of nature still held by natural philosophers. Both Copernicus and Vesalius offered alternative views for succeeding generations that checked data against authoritative ancient texts, impervious to modifications so common among scribal texts that could not

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[159] Elizabeth Eisenstein, *The Printing Press as an Agent of Change*, Vol. 2, 570–572.

have occurred without the printing press. They were among the first scientific thinkers to develop theories on subject matters via reason and personal observation in an era when scholastic endeavors discouraged individual thought. The availability and diversity of texts, provided by the printing press, allowed for the recognition that what had previously been taught might have been erroneous. Ironically, the effects of the widespread availability of texts from the ancients also induced skepticism because reliance on the texts suggested dependent thinking.

Galileo exemplifies this well in his discourse with Salviati, the layman/spokesperson in his *Dialogue Concerning the Two Chief World Systems*, disparaging intellectuals who paid homage to the ancient philosophers, such as Aristotle, by revealing the fallacies in their principles and illustrating that thinking for oneself reflects true scholarship. The important book to read was the Book of Nature—a motivating factor in the development of science. As Steven Shapin reminds us, the evidence of nature's reality superseded the authority of a text as the study of science took root. Modern natural philosophers of the period often referenced the Book of Nature. William Gilbert called it a "new style of philosophizing," and dedicated his book on magnetism to "true philosophers, ingenious minds, who not only in books but in things themselves look for knowledge."[160] Galileo, in *The Assayer*, argued that natural philosophy should be mathematical in form because nature was inherently mathematical:

> Philosophy is written in this grand book, the universe, which stands continually open to our gaze, but it cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written. It is written in the language of mathematics, and its characters are triangles, circles and

[160] Quoted in Steven Shapin, *The Scientific Revolution* (Chicago: University of Chicago Press, 1996), 68.

> other geometrical figures, without which it is humanly impossible to understand a single word of it; without these, one is wandering around in a dark labyrinth.[161]

This is not to say that texts from the ancients were ignored, but the implication that personal observation was relevant is paramount for understanding Europe's development of modern science. Benjamin A. Elman, a professor of Chinese Studies at Princeton University, describes this well in terms of Kepler and Newton being both humanists and scientists because they interpreted references to natural phenomena in classical texts and used astronomy to date events in ancient history. Although Kepler and Newton persisted in extrapolating new data from direct observation and experimentation, "humanist scholarship and science were a single pursuit."[162]

Eisenstein tells us that early printed classical works were often as corrupted as those produced by scribes, but as printers had to compete with one another in gaining profits, they also sought to eliminate and rectify corruptions by comparing early scribal reference works with earlier printed editions, thereby diminishing some corruptions. Although as Eisenstein notes, many sixteenth-century printers merely replicated old compendia wrought with errors, others "created vast networks of correspondents and solicited criticism of each edition," leading to new works, research and new data. This "furthered interchanges which set off new investigations" and expanded scholarship that would have been impossible through scribal works alone.[163] It was not necessarily the introduction of printing itself that produced the Scientific Revolution, but "how it

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161 Galileo Galilei and Stillman Drake, *Discoveries and Opinions of Galileo: Including the Starry Messenger (1610), Letter to the Grand Duchess Christina (1615), and Excerpts from Letters on Sunspots (1613), The Assayer (1623)* (New York: Anchor, 1990), 237–238.

162 Benjamin A. Elman, "Global Science and Comparative History: Jesuits, Science, and Philology in China and Europe, 1550–1850," *EASTM* 26 (2007), 15.

163 Elizabeth Eisenstein, *The Printing Revolution in Early Modern Europe* (New York: Cambridge University Press, 1983), 74–76.

went on to function in society is the crucial variable" in explaining how printing aided the advent of modern science.[164]

With respect to the Needham Question, the tradition in China of comparing ancient works in order to critically react to errors and inaccuracies was quite different and was not a direct result of printing technology as Eisenstein advocates for Europe—although printing did enhance the evidential scholarship movement, or *kaozheng*, underway by the middle of the Qing dynasty (1644–1911). This movement prompted many scholars to question the authority of the orthodox classics prevalent during the Song and Ming dynasties. *Kaozheng* scholars sought to better comprehend the original principles of the sage-kings by revisiting the actual classical commentaries dating from the Han period, bypassing the Neo-Confucian commentaries, aiming at recovering the meaning of the classics, which were subject to critical scrutiny.[165] Distinguishing discrepancies in texts was prevalent, but not in terms of discovering transmitted scientific inaccuracies as in Europe, where scholars of the period were inclined to prove the ancients wrong, such as Vesalius in disproving Galenic illustrations mentioned earlier or Kepler in challenging Tycho's planetary observations. Instead, *kaozheng* represented precise scholarship whereby the relevance of the past was validated and Qing literati attempted to rid the empire of *Daoxue* scholarship, which was considered abstract, containing inaccurate interpretations of the classical Han texts.[166] In practicing evidentiary research, intellectuals emphasized careful textual study and meticulously evaluated data based on rigorous standards in mathematics, astronomy, geography and linguistics

[164] H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry,* 476.

[165] Benjamin A. Elman, *From Philosophy to Philology: Intellectual and Social Aspects of Change in Late Imperial China* (Cambridge, MA: Council on East Asian Studies, 1984), 28–29.

[166] Ibid., 30.

in order to understand what the sage-kings had meant, allowing for a better understanding of how to live in the present.[167] According to Jonathan D. Spence, *kaozheng* methodology encouraged sharp explorations of the past with a "penetrating skepticism" where scholars detailed and accumulated specific facts that influenced hydraulics, cartography and ancient texts on government which allowed the Qing to more accurately scrutinize their reality.[168] By the 1750s, *kaozheng* scholarship was influential and heavily supported by the printing industry since advanced research required numerous texts for analysis. Often merchants became patrons of *kaozheng* scholarship, amassing large libraries which were at the disposal of scholars. Philologists were able to demonstrate their reverence for the ancients by recovering lost texts and removing inaccuracies and corruptions that had accumulated throughout previous dynasties, and reprinting texts considered to be accurate.[169] Emperor Qianlong (1735–1796) actively promoted scholarly projects, and the palace collection in the Forbidden City—also where the Imperial Printing Press was located—became a repository for many surviving Ming texts that *kaozheng* scholars were able to use in order to reconstruct traditional Chinese mathematics. During the reign of Emperor Kangxi (1661–1722), more than 15,000 books of all genres were published using mostly moveable type printing.[170]

Since printing was first introduced in China, Eisenstein sees the Chinese experience with paper and printing as a testing ground for explaining the Scientific Revolution in Europe. H.

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[167] Ibid., 36.

[168] Jonathan D. Spence, *The Search for Modern China*, 104.

[169] Benjamin A. Elman, *From Philosophy to Philology: Intellectual and Social Aspects of Change in Late Imperial China,* 207–208.

[170] Benjamin A. Elman, *A Cultural History of Modern Science in China*, 86–88.

Floris Cohen agrees and relates Needham's point that, in China, early texts were printed on "flimsy" paper that had possibly disintegrated so that much of what had been written was lost before the mass production of printing. He speculates that in times of inner political struggles and disorder wrought by foreign conquests, whole editions of printed books were destroyed, and would have been lost anyway even if China had had mass printing.[171] In the *Grand Titration*, Needham relates this concept to medieval cultures in general in that much that has been written has been lost in both eastern and western societies. In noting the complexities of technologies in China, such as textile machines or the water-wheel link work escapement clocks, he surmises that long periods of workshop experimentation, by trial and error, must have ensued.[172] The fact that no documentation exists about this experimentation, and speculating on what texts may have said if they had or had not been published or destroyed, can never aid the modern historian to fully answer the Needham Question. Such speculation, however, is relative to evidentiary research, especially considering the Chinese revival of mathematical texts during the Ming and later the Qing. According to Elman, the Ming could no longer comprehend the methods used by Song mathematicians for solving polynomial equations and sought to rectify this, and to prove that the knowledge brought to China by the Jesuits must have already been known by ancient Chinese scholars. This led Qing mathematicians and astronomers, like MEI Wending, to undertake large-scale efforts to recover and collate long forgotten Chinese mathematical texts, which

[171] Joseph Needham, *Clerks and Craftsmen in China and the West*. Lectures and Addresses on the History of Science and Technology. Based largely on collaborative work with WANG Ling, LU Gwei-Djen, and HO Ping-Yü (New York: Cambridge University Press, New York, 1970), 24.

[172] Joseph Needham, *The Grand Titration*, 50.

were believed to have developed similarly in Europe, but separately.[173] Literary projects increased under Song rule, but the content of what was being printed differed from that of Europe, since much of it was mainly Confucian doctrines and material written for political purposes in order to exert control over the civil service examinations. Even under the Ming dynasty, printing was a means of circulating ideas favorable to the state. Historian of Chinese science Catherine Jami notes that Chinese imperial governments had always had interests in fields such as botany and geography. The Ming, too, attempted to integrate medicine and mathematics into the imperial examination curricula, but integration remained within the realm of Confucian scholarship, and the material that was published—at least in medicine and mathematics—consisted of books that were translated and compiled, excluding texts that resulted in direct observation and experimentation. [174]

What historians do know, however, is that scholars in China were hesitant to question the ancient texts they revered, unlike the Europeans, until the overthrow of the imperial Qing government (1644–1912). In many ways, this is relevant to Needham's view that the social conditions in China were not favorable for a scientific revolution and were distinct from the West. As Francis Bacon had forecast in the *New Atlantis*, scientific institutions inherited the Church's claim over knowledge. Yet, the Scientific Revolution helped redefine scientific knowledge, promoting the view that "knowledge [was] related to human individuality and to the active rela-

[173] Benjamin A. Elman, *A Cultural History of Modern Science in China* (Cambridge, MA: Harvard University Press, 2006), 57–58.

[174] Catherine Jami, "Introduction to Science in Early Modern East Asia: State patronage, Circulation, and the Production of Books," *Early Science and Medicine* 8, no. 2 (2003), 86.

tions of man and nature."[175] As Sivin points out, the Chinese mindset of the seventeenth century "considered the idea of objective knowledge without wisdom, without moral or esthetic significance, grotesque."[176] To further this insight, Wen-yuan QIAN maintains that China remained descriptive while the West explained nature with mathematics. He links Europe's scientific progress to its desire to conquer nature, whereas the Chinese notion of ataraxia, contained in Confucian, Daoist and Buddhist thought, favored one personally turning inward for the attainment of equanimity and calmness, rather than outward toward the material world and the cosmos. This inward looking discouraged independent thinking, and innovative scholarship was limited.[177] As T.H. TSIEN remarked, a culture's readiness for an invention is not only physical, but also mental. Printing in China had strong moral implications because of reverence for ancient learning and was closely connected to the veneration of one's ancestors. Printing was also motivated by the need for great quantities of religious texts specifically for the revival and maintenance of Confucian learning. There is a strong correlation between the number of books printed in China and the number of imperial exams taken under any given dynasty.[178] Needham and many other scholars have stressed Confucianism's impediment to China developing modern science because it discouraged individual thinking and encouraged social and intellectual conformity. It also inhibited critical thinking and is one major difference between the East and the West in developing science.

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[175] Nathan Sivin, *Science in Ancient China,* 61.

[176] Ibid., 63.

[177] Wen-yuan QIAN, *The Great Inertia: Scientific Stagnation in Ancient China,* 101–102.

[178] TSIEN Tsuen-Hsuin, *Collected Writings on Chinese Culture,* 380.

While western intellectuals, too, at least in Catholic countries, had to conform to the mandates and the authority of the papacy, the printing press in Europe unleashed a pandora's box. In Europe, printing became an economic incentive and contributed to the merchant class which was closely controlled in China. The printing of newly discovered ancient works transcribed manually and then printed, allowed for wider dissemination and scrutiny because finally comparisons among texts could be made, and textual discrepancies analyzed, which fostered inquiry, criticism, and the collection of new data to further eliminate errors. Although during the Song, there was a flourishing of printing, it was still controlled by the state even during the rise of the Ming. Seung-Hwan MUN, a professor of media studies at Northeastern Illinois University, calls printing in China the "cut and paste" method, where classical works were merely reprinted.[179] In the West, Galenic illustrations gave way to more accurate Vesalian anatomical illustrations produced via woodblock printing, a technique exploited in China centuries earlier.

Why the Chinese did not develop more illustrative accuracy in scientific anatomical or botanical works is a question to ponder. Or, as Needham suggests in *The Grand Titration*, perhaps they did publish these pieces, but they were lost because of dynastic turmoil and natural disasters. The Chinese did look toward nature, but perceived themselves as organically one with nature. The Europeans began to look at the universe via the Book of Nature, seeing themselves as part of nature—but not necessarily one with nature because nature was something they could conquer and mathematically decipher. As noted, the printing press enabled Europeans to expand upon and exploit the social instability already brewing among intellectuals since the late Renais-

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[179] Seung-Hwan MUN, "Printing Press with copyright: a historical analysis of printing and publishing in Song, China," 16.

sance. There was instability in China, too, but instead of intellectuals using this to their advantage to develop scientific theory, they adhered and conformed to their imperial authorities. The printing press only manifested this conformity in China. The Grand Question, in my view, is not only why did the Chinese never develop modern science, but why did they not compare textual inaccuracies in astronomy or mathematics, considering the new knowledge brought by the Jesuits, and develop more scientific data from observation and experimentation rather than try to prove that this scholarship had previously existed, or had since been lost. Why did they seldom question authority and not envision the larger world beyond their own borders? The introduction of the printing press in Europe cultivated an intellectual uprising and directly fostered the Scientific Revolution, but this did not occur in China until much later.

Chapter IV

CULTURAL FACTORS: THE IMPERIAL EXAMINATION SYSTEM IN CHINA

> It is evident to everyone here that no one will labor to attain proficiency in mathematics or in medicine who has any hope of becoming prominent in the field of philosophy. The result is that scarcely any one devotes himself to these studies, unless he is deterred from the pursuit of what are considered to be the 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.
>
> —Nicholas Trigault (1577–1628)[180]

Another way to assess the Needham Question is by understanding the influences of the imperial civil service examination system and its long-term repercussions on Chinese society. Often referred to as China's fifth great invention, the civil service examinations, known as *keju*, occupied a unique place in Chinese history with the distinctive role of recruiting officials for its complex bureaucratic institutions until its abolition in 1905. To some scholars, the examination system positively contributed to China's continuous solidification as a nation because it helped maintain political unity and preserve Chinese culture. For over two thousand years, China has

[180] Nicholas Trigault, Jesuit Missionary in China, quoted from Louis J. Galligher, *China in the Sixteenth Century: The Journals of Matteo Ricci, 1583–1610*, by William Theodore de Bary and Ricard Lufrano, eds. *Sources of Chinese Tradition, Vol. 2: from 1600 Through the Twentieth Century* (New York: Columbia University Press, 2010), 65.

remained an independent and homogenous civilization even though it had been prone to a number of invasions by the Huns, Mongols, Tartars and Manchus. For many centuries, China maintained commercial trade with the Roman Empire and records indicate that at the beginning of the sixth century, Buddhist priests from India and other parts of central Asia routinely traversed the region.[181] Since the thirteenth century, there has been contact with Europe which continues to this day. Following the Jesuit missionaries and later, the nineteenth-century Protestant missionaries, China suffered invasion by the Japanese during WWII and thereafter, was dominated by Maoist cultural and political reforms in the twentieth century. Today, China is unified with a strong centralized government and education system, a progressive economy and a powerful military.

What is unique about China is that it has never broken into disparate cultural and political groups such as in Europe or other parts of the world. The preservation of China's uniformity may be attributed to its social and political structures which, in part, were shaped by the civil service examination system. Passing the bureaucratic examinations was the primary gateway to political appointment and social mobility, attaining social and educational prestige and economic success. Entrance to circles of upper-class status otherwise was not achievable. At the same time, the examination system was an obstacle to China realizing scientific and technological advancement and industrial progress. In this chapter, I will argue that the imperial examination system in China was an impediment to scientific growth and the development of a scientific revolution because qualifying and passing the imperial examinations held more prestige than did the

[181] Paul F. Cressey, "The Influence of the Literary Examination System on the Development of Chinese Civilization," *American Journal of Sociology* 35, No. 2 (1929), 250–251.

pursuit of the natural sciences. Moreover, the examinations required inordinate preparation — leaving little time for the pursuit of other studies, and the examination curriculum itself largely contained materials pertaining to Confucian orthodoxy in order for dynasties to maintain control and resolve social problems, with little attention being paid to science and mathematics.

The imperial examination system was always a central component in Chinese society, going through many modifications in each dynasty, but it remained similar in structure throughout its history. Successive dynastic regimes ranked candidates and graduates hierarchically according to the degree of their success and the privileges granted them were relegated accordingly. Traditionally, the imperial examinations were given in four stages, beginning at the prefectoral level where one earned the *xiucai* degree or "cultivated talent," similar to an American Bachelor's degree, which preceded the provincial *juren* degree or "recommended man." Acquiring one or both of these degrees permitted examinees to attain lower to middle-ranking positions in government with state-granted privileges that ranged from protection against corporeal punishment to physical labor exemptions, government remunerations, the codification of a specific dress code and the ability to marry outside one's social status.[182] If an examination candidate passed the first two tiers, the next examination competition was at the the metropolitan level where one could earn the *jinshi* degree at the palace level, where few were successful. However, those who passed were accorded eligibility for more elevated positions in the imperial bureaucracy. Passing these three examinations allowed candidates to engage in teaching and administer-

[182] John W. Chaffee, *Thorny Gates of Learning in Sung China: A Social History of Examinations*, 4–7.

ing the exams to other candidates in addition to other official positions of varying ranks.[183] If one passed to the fourth stage of the examinations, the ultimate *jinshi* degree, the top imperial level, administered every three years, the emperor himself would respectfully address the candidates with an introduction:

> You graduates are talented men who have qualified in repeated examinations and now, facing the palace examinations, are about to answer My questions. I am the Son of Heaven, responsible for governing the Empire. Night and day I rack my brains so that the people will be able to live in tranquility. Fortunately, I have this opportunity to pose questions to you graduates and I wish to hear your well-considered opinions on the following.[184]

Upon success, one was admitted to the *hanlin*, or "the forest of the pencils," which constituted the Imperial Academy of Letters, the highest honorary title with which one automatically received one of the highest-ranking positions in the government.[185] Theoretically, any adult male in Chinese society, regardless of his lineage or wealth, could attain these positions if he passed through the various levels of the examination process. There were no social or class restrictions unless within the last three generations the candidate's family had engaged in activities deemed base, such as running a brothel or committing serious crimes.[186] Although the probability of passing the examinations was low and the prospects of gaining high-ranking status were slim, the

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[183] Hilde De Weerdt, *Competition over Content: Negotiating Standards for the Civil Service Examinations in Imperial China (1127–1279)* (Cambridge, MA: Harvard University Press, 2007), 2–6.

[184] Ichisada Miyazaki, *China's Examination Hell: The Civil Service Examinations of China* (New Haven: Yale University Press, 1991), 77.

[185] Paul Cressey "The Influence of the Literary Examination System on the Development of Chinese Civilization," 257.

[186] Ichisada Miyazaki, *China's Examination Hell: The Civil Service Examinations of Imperial China*, 19.

numbers of candidates attempting to qualify for the examinations continually increased because of the elite status granted to candidates. Participation in the examination process was appealing because of its function as a social marker, distinguishing the non-literati from the literati. One estimate suggests that candidates sitting for the examinations rose from 20,000 to 30,000 in the early eleventh century, reaching 400,000 by the middle of the thirteenth century, with most candidates who actually passed, receiving the *juren*.[187]

Being a government official in Chinese society meant that you were highly regarded both socially and politically. Early Portuguese explorers noted the special status or "aura" of Chinese government officials in their abilities to command respect, calling them mandarins from the Portuguese word, *mandar,* to command. Achieving the rank and status of a mandarin was the goal of many Chinese youth. Max Weber, in commenting on Chinese society, notes the unique status of the mandarin:

> In the eyes of the Chinese masses, a successfully examined candidate and official was by no means a mere applicant for office, qualified by knowledge. He was a proven holder of magical qualities…..which were attached to the certified mandarin just as much as to an examined and ordained priest of an ecclesiastic institution of grace, or to a magician tried and proved by his guild.[188]

Qualifying for and passing the imperial examinations not only meant social advancement, it also meant public prestige. To paraphrase Ichisada Miyazaki, a former professor of Oriental History at Kyoto University, graduates dined with imperial officials at elaborate banquets and were ceremoniously paraded down public roads near the palace commemorating their achievements.

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[187] Hilde De Weerdt, *Competition over Content: Negotiating Standards for the Civil Service Examinations in Imperial China (1127–1279),* 7–9.

[188] Quoted in Frank Swetz and Albert CHI, "Mathematics Entrance Examinations in Chinese Institutions of Higher Education," *Educational Studies in Mathematics* 14, no. 1 (February, 1983), 39.

Graduates were rewarded financially and allowed to build arches of triumph in front of their residences. On columns near the Imperial Academy, graduates' names were inscribed indicating their special status.[189] During the late Ming and Qing periods, palace graduates were expected to bestow the emperors with a "memorial of gratitude," or *xiebiao,* symbolizing their first duty as an official.[190] Graduates were accorded the prospects of marrying the daughters of other high-ranking officials even if the graduate originally came from a humble background. Financial and legal rewards were abundant and granted not only to the graduates, but also to the licentiate, or the student who took part in the examination system, simply because he had access to the imperial world. The families of candidates and graduates also gained prestige and rank, so focusing on the examinations took precedence over studying other subjects.[191] Failure to qualify or pass also marked students and their families negatively because failure was often perceived as a result of past immoral behavior. Not doing well was considered an indicator of bad karma or possibly the result of scorned women returning form the dead, who sought revenge by haunting examination halls.[192]

Owing to the pressures of the examinations, many families of candidates, and at times often the candidates themselves, resorted to divination, geomancy, and dream interpretation in attempts to predict examination success—a manifestation of cultural norms that were continually

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[189] Ichisada Miyazaki, *China's Examination Hell: The civil Service Examinations of Imperial China,* 85–87.

[190] Benjamin A. Elman, *Civil Examinations and Meritocracy in Late Imperial China* (Cambridge, MA: Harvard University Press, 2013), 23.

[191] Ibid*.,* 90.

[192] Jonathan D. Spence, *God's Chinese Son: The Taiping Heavenly Kingdom of Hong Xiuquan* (New York: W.W. Norton and Company, 1997), 45.

reproduced throughout the dynasties. However, many metropolitan and provincial examiners attempted to distance themselves from prognostication by asking questions about natural anomalies, such as earthquakes or floods, and how such events could be accounted for. This often overlapped with official dynastic beliefs that dealt directly or indirectly with the natural world because natural disasters were thought to have been the result of dynastic mismanagement or errors in the calendar, which was the responsibility of the imperial court.[193] In effect, the imperial examination questions had to reflect the cosmological perspectives of the dynasty which mediated the principles between the celestial spheres and human affairs on earth, which were theoretically unified according to Confucian orthodoxy. Both examinees and examiners had to recognize the limitations in the human comprehension of the cosmos. To impute the meaning of calamities via prognostication presumed human ignorance and implied resignation. For orthodox literati, this was unacceptable because the symbolic meaning of a calamity was insignificant, but the concrete government policies implemented to rectify natural calamities were relevant, since governance by humans took precedence over the workings of the heavens and were beyond what man could comprehend.[194]

Preparing for the examinations was a major preoccupation of students wishing to serve in the government's bureaucracy—a view that persisted throughout successive dynasties. Preparation began as a young adolescent, continuing until one's mid-thirties, but with no guarantee of success. In order to reach the palace level examinations, examinees endured extraordinary hours of preparation. It was common for an eight-year-old boy to enter school (with preparation occur-

[193] Benjamin A. Elman, *A Cultural History of Civil Examinations in Imperial China*, 346–348.
[194] Ibid., 354.

ring in the home even before this age with a private tutor if the family could afford it), with the expectation of memorizing well over 400,000 Chinese characters from the *Five Classics* and the *Four Books* before the age of fifteen, at the rate of two hundred characters per day. In addition to memorizing the ancient texts, they were expected to read commentaries, answer practice examination questions, and compose poems and essays modeled on previous answers to examinations. Students were also expected to master the Dynastic *Histories*, and by the Qing Dynasty, there were twenty-two such printed works.[195] The texts, memorized by rote, were written in Classical Chinese. Students were forced to learn a second language because often their first language was a contemporary vernacular Chinese containing different grammatical forms and characters. Students were also accustomed to learning Mandarin (and there were southern and northern Mandarin dialects) if they were to communicate with the bureaucracy.[196] In essence, this left little time for a student, whether young or old, to pursue other studies or interests such as in the natural sciences. In Miyazaki's view, the difficulties of test-taking were extremely pronounced because exact answers had to be replicated from study materials and the materials themselves were often vague, with candidates not fully knowing what to specify in their answers. Having basic knowledge of the natural sciences or mathematics was customary for some officials in performing certain duties, but expertise was not required because these disciplines were associated with either the merchant or the working classes.[197]

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[195] Ichisada Miyazaki, *China's Examination Hell: The Civil Service Examinations of Imperial China,*16.

[196] Benjamin A. Elman, *A Cultural History of Civil Examinations in Late Imperial China,* 381.

[197] Ichisada Miyazaki, *China's Examination Hell: The Civil Service Examinations of Imperial China*, 19–21

In general, the curriculum of the imperial exams remained constant throughout the dynasties, with minor variations occurring under different reigns pertaining to practical and legal knowledge. It entailed the *Four Books,* containing texts attributed to Confucius, and commentary chapters by ZENG Zi, a disciple of Confucius; the *Doctrine of the Man*, which demonstrates the means to perfect virtue laid down by ancient rulers; the *Analects,* a compilation of Confucius' speeches; and the works of Mencius, his discourse with the kings of his day containing extensive prose and lengthy dialogues. In addition to the *Four Books*, students were also expected to memorize the entirety of the Dynastic *Histories* and the *Five Classics*, i.e., the *Classics of Poetry*, containing over 300 poems; the *Book of Documents,* pertaining to documents dating as far back as the 6th century B.C.E.; the *Book of Rites*, describing ancient rites and ceremonies; the *Book of Changes*, describing China's system of divination; and the *Spring and Autumn Annals,* a historical record of the state of Lu, Confucius' native state. Writing in 1030, chief counselor, FAN Chung-yen (*Fan Zhong Yan*), concluded that this particular curriculum guaranteed political and social wisdom and would improve the country. Learning the classics was considered the pinnacle of a moral mind and led to *Dauxue*, which in turn, led to men gaining talent and achievement. Men gained refinement and wisdom and "thus [were] able to submit to the record of regulations, investigate the methods of pacifying dangers, set out the mirror for seeing gains and losses, analyze the discrimination of truth and falsehood, and understand the ordering of the world [and] cause their followers to help complete the Way of the Kings."[198]

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[198] John W. Chaffee, *The Thorny Gates of Learning in Sung China: A Social History of Examinations*, 4–6.

After 1465, the eight-legged essay was officially implemented as part of the curriculum and increased the difficulties of mastering the exams. It became an instrument to further determine a candidate's qualifications and to deflect flaws in the system itself, remaining well into Qing dynasty. It was a rigid, formulaic parallel-prose style essay with eight parts written on the *Four Books* and the *Five Classics,* limited to between 500 characters during the Ming and 700 in the Qing. It was structured in a grid-like fashion, divided into columns and rows, making it easier for examiners to grade according to a strict rubric. If a candidate did not follow the rules of balancing the length of his essay, or if he had one misplaced character or too many characters, he would be disqualified.[199] According to some scholars, the eight-legged essay further contributed to China's backwardness regarding not only industrialization, but more importantly, to China's failure to develop science and technology in contrast to Europe's achievements because its formulaic structure compelled uniformity and de-emphasized critical thinking in favor of rote learning, which often did not prepare a candidate to adequately function in an official position.[200] Although officials were expected to comprehend some of the basics in astronomy, mathematics, calendrical and musical studies, their comprehension was "part of the orthodox apparatus of ritual" and officials were not expected to focus on science, but to understand "the role of natural science in governance."[201]

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199 Benjamin A. Elman, *Civil Examinations and Meritocracy in Late Imperial China*, 62.

200 Hilde De Weerdt, *Competition over Content: Negotiating Standards for the Civil Service Examinations in Imperial China*, 66–67.

201 Benjamin A. Elman, "From Pre-modern Chinese Natural Studies to Modern Science in China." *Mapping Meanings: The Field of New Learning in Late Qing China*. Editors Michael Lackner and Natascha Vittinghoff (Leiden, Netherlands: Koninklijke Brill NV, 2004), 40.

After Qin unification in 221 B.C.E., the Chinese state was ruled by an imperial bureaucracy and in the seventh century onward, from the Sui Dynasty to the beginning of the collapse of the imperial order in the early twentieth century, the imperial examinations were the fundamental channels for gaining access to officialdom. The examination system developed gradually, stemming from some of the more distinctive cultural mores in Chinese society especially related to Confucian doctrines that "well serve as a barometer by which the tenor of historical China's socio-political, economic and intellectual climate can be gauged."[202] Initially, the Han dynasty, considered a period of disunity, used the examination system as a means for testing men that had already received official recommendation for political positions—recommendations most often based on familial relations connected to the aristocracy. Those selected for testing engaged in a course of study, embracing the imperial ideology that served to legitimate the political sovereignty of the state. The candidates answered exam questions orally based on urgent concerns relevant to state policy. Only thirty-six examinees, or about five per cent of those tested, passed these exams during the Han.[203]

The Sui Dynasty officially established and consolidated the imperial examinations in order for the emperor to assert authority over the old aristocratic families that had dominated Chinese society during the preceding Han period. Eventually, the established aristocratic families were delegitimized, but still dominated many official positions and remained a threat to centralized power.[204] During the Tang regime, the examination system matured and served as a vehicle

[202] Jonathan LU,"Reassessing the Needham Question: What Forces Impeded the Development of Modern Science in China after the 15th Century," 41.

[203] Ibid., 42.

[204] Benjamin A. Elman, *A Cultural History of Civil Examinations in Late Imperial China*, 5–6.

for widening the social backgrounds of bureaucratic officials. In order to qualify for the exams under the Tang, candidates were expected to have higher degrees of literary skills than under the Sui. The qualification process called *hsuan-chu (xuan chu)*, required knowledge of the Confucian classics, but also tested one's character, deportment, eloquence, calligraphy and legal knowledge. These attributes determined official appointments, but most appointments were of men residing in the capital based on court patronage and not always based on success in the examinations. The new political subgroups of degree holders during the Tang were still marginalized and official positions were dominated by aristocratic families who based their claims to power on lineage and the desire to preserve ancient Chinese aristocratic traditions.[205] It did not go unnoticed under the Tang, and most notably during the reign of Empress Wu (625-705 C.E.), that the examinations still enabled entrenched aristocratic families to maintain hereditary control over state politics. In 737 C.E., the Ministry of Rites took over the selection process from the Ministry of Personnel in order to reduce unfairness in the system, but this had little impact since eligible candidates not only stemmed from the aristocracy, but from the literati, who determined success in the examinations. The questions were classical and literary and required candidates to cite a text from memory or to write in missing characters that had tags placed over the texts. During the later part of the Tang, questions related to Daoism were implemented regarding policy questions, and the concepts of nature were applied, but were later abolished.[206]

By the Song dynasty, the civil service examinations were elaborately modified and became a major recruitment tool, often corresponding to changes occurring in the dynasty, whose

[205] Hilde De Weerdt, *Competition over Content: Negotiating Standards for the Civil Service Examinations in Imperial China (1127–1279),* 17.

[206] Benjamin A. Elman, *A Cultural History of Civil Examinations in Late Imperial China*, 7–12.

focus was on a successful, unified state that lacked expansionist visions. Since the first Song emperor's reevaluation of the examinations, the imperial examinations began to convey more respect because they were now the primary gateway to officialdom and top posts. During the first half of the dynasty, high-ranking court officials and government positions at the local levels were dominated by the strongest aristocratic families, who were centered in the northwest near the Wei River Valley. In 1127, the northern city of Kaifeng was captured by the Jurchen Jin empire and the Song court fled to its new capital, Hangzhou, south of the Wei River, in 1132.[207] Northern court officials, servants, soldiers and commoners alike were dislocated. Aristocratic families held less prominence and control, and established alliances with local families in the south, often via marriage. Obtaining power was related to other factors such as land ownership and monetary wealth in addition to the possibility of examination success similar to previous eras, but less so. Instead of aspiring toward imperial ambitions, at least temporarily, many of the leading families created social welfare projects, including agricultural enterprises that steadily prospered due to new techniques in rice production. In addition to industrial development, the cash economy grew, and the collection of taxes increased, leading to monetary growth.[208]

Although Song society was in upheaval politically, especially during the transition between the Northern and the Southern Song when the dynasty's existence was threatened by Jurchen Jin and Mongol invaders, John W. Chaffee considers this particular crisis period of "ad hoc measures" the precise moment when the imperial examination topics were expanded and be-

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[207] John W. Chaffee, "Examination During Dynastic Crisis: The Case of the Early Southern Song," *Journal of Song-Yuan Studies* 37 (2007), 135. John W. Chaffee is a social historian who specializes on the Song dynasty at SUNY/Binghamton.

[208] Hilde De Weerdt, *Competition over Content: Negotiating Standards for the Civil Service Examinations in Imperial China (1127–1279),* 10.

came more elaborate. They were reconstituted, incessantly debated, and curriculum guidelines were established that remained in place well into the nineteenth century. In response to the precarious military situation, prefectural officials were asked to recommend men with military skills and knowledge of military texts.[209] In view of the Jurchen Jin sieges of Kaifeng, examination candidates were often recruited if they had military expertise, with the recruitment process being sped up in order to change the political landscape. Candidates were expected to compose abstract discussions on political and philosophical principles and respond to technical problems involving government.[210] Chaffee, too, notes that by the thirteenth century, there were several hundred thousand examination candidates whereas in the eleventh century, there were only several tens of thousands. Such an increase in the numbers of candidates, however, limited opportunities for bureaucratic positions because of increased competition among examinees, as there were only a certain number of positions available, which, in effect, limited social mobility.[211] Yet, as Chaffee also notes, the imperial examinations never lost their appeal because of their function as an elite status marker.[212]

By 1250, the empire had transitioned entirely to the southern realms and Southern Song dominance emerged, where the "best and the brightest" aided in changing the composition of China's governance. The imperial examinations became more widely available to candidates

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[209] John W. Chaffee "Examination During the Dynastic Crisis: The Case of the Early Southern Song," 136–137.

[210] Hilde De Weerdt, *Competition over Content: Negotiating Standards for the Civil Service Examinations in Imperial China (1127–1279),* 13.

[211] John W. Chaffee, *The Thorny Gates of Learning in Sung China: A Social History of Examinations* (Cambridge, UK: Cambridge University Press, 1985), 17.

[212] Ibid., 188.

outside of the landed and aristocratic families and hereditary privilege no longer guaranteed success, socially or politically, as in previous eras. The examinations, in a sense, were legitimized or democratized and became more objective and transparent.[213] Despite the reign's tumult and its fear of further outside invasions, the period is still considered an era of great flourishing in both science and technology, when printed publications began to proliferate, and private printing houses sprang up throughout the empire. In addition to texts being published on history, the classics and poetry, books on medicine, geography and mathematics also appeared. However, these publications had less effect on the subject matter of the civil examinations than one would expect and pertained more to the cultural life of the empire. Although the majority of the examination questions focused on Confucian classics and Daoism, there were a few policy questions at the Imperial Academy, or *Guo Ziyi*, on a variety of problems regarding insufficiently stocked granaries, poor revenues, unlawfulness and external natural disasters. Examinees were expected to respond in ways which reflected how officials and the examinees themselves may have failed regarding these problems in society and to come up with possible solutions.[214] Chaffee notes a particular examination question which characterizes this sentiment:

> Is it my lack of virtue that makes us unable to move Heaven, or is it that the political directives were inappropriate and caused the people to suffer? Why is it that absolute sincerity is ineffective and calamities are hard to suppress? If one wishes to restore one's lineage, settle border affairs, eliminate the evils of banditry, improve customs, make the common people secure in their occup-

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[213]Ichisada Miyazaki, *China's Examination Hell: The Civil Service Examinations of Imperial China,* 9–11.

[214] John W. Chaffee, "Examinations During Dynastic Crisis: the Case of the Early Southern Song," 143.

> ations, and unweariedly achieve the establishment of order, what must be done to achieve this?[215]

SHEN Kuo wrote that during the Huang Yu reign (1049–53), examination candidates were asked to prepare essays on some mathematics and astronomical instruments, but the essays were so ambiguous and the examiners themselves somewhat ignorant on the subjects that most of the candidates still passed with distinction in many cases.

As examination culture moved toward a more ethical-philosophical discourse characteristic of *Daoxue,* the structure of China's bureaucratic examination culture also slowly changed. Beginning with the Song, even though standard commentaries from the seventh century were still used on the examinations, more imaginative and more liberal interpretations of classical learning emerged that were, in part, "derived from classical responses to Buddhist challenges."[216] Elman notes that WANG Anshi's failure to reform the Song dynasty in the 1060s and 1070s led scholar-officials such as CHENG Yi (1033–1107) and CHENG Hao (1032–1085) to reconsider the state's political and economic agendas, favoring a return to a conservative moral agenda that stressed an individual's character development. Their teachings asserted that the moral cultivation of the literati was the foundation for self awareness which would improve one's family and lineage, and above all, would positively affect the state.[217] The *Daoxue* teachings of CHENG Yi and CHENG Hao, both brothers, with their philosophy being later known as the Cheng-Zhu

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[215] Ibid., 144.

[216] Benjamin A. Elman, "Unintended Consequences of Classical Literacies for the Early Modern Chinese Civil Examinations," in *Rethinking East Asian Languages, Vernaculars, and Literacies, 1000–1919*, ed. Benjamin A. Elman (Leiden: Koninklijke Brill NV, 2014), 199.

[217] Benjamin A. Elman, *Civil Service Examinations and Meritocracy in Late Imperial China,* 14–16.

principle of learning associated with the Cheng-Zhu school of Neo-Confucianism, stressed the capability of the human individual in reaching the moral high ground of life, and greatly impacted classical learning.[218] After the northern Song capital fell in 1127, the dynasty moved south to the ocean port of Hangzhou. No longer surrounded by the Khitan Liao (916–1125) and the Jurchen Jin (1115–1234) dynasties in the northern and eastern parts of China, the Song was able to claim itself as successor to the Tang. As the dynasty politically transitioned to what is known as the Southern Song (1127–1280), the literati shifted toward a more autonomous role, using *Daoxue* to illustrate how they, the literati, represented moral cultivation whereas the emperor, or the dynasty itself, did not.[219]

Another influential scholar associated with the Cheng-Zhu school, ZHU Xi (1130–1200), greatly influenced the civil service examinations. First, ZHU Xi helped create a new tradition which emphasized the *Four Books*, containing the *Analects*, *Mencius*, *The Great Learning*, and *The Doctrine of the Mean,* as the core curriculum for the imperial examinations. He stressed that students should read the *Four Books* rather than the *Five Classics,* in order to better understand the original intent of the Confucian classics and not focus on philology and the authenticity of a text, which was the focal point when reading the *Five Classics*. ZHU Xi's emphasis on the *Four Books* stressed a moral and holistic approach to attaining knowledge where memorization was deemed secondary. ZHU Xi also wrote an extensive commentary on the *Four Books,* called the *Si Shu Ji Zhu,* or the *Collected Commentaries on the Four Books*—considered the most influential book since the twelfth century and decreed as the standard reference for the civil service ex-

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[218] Thomas H.C. LEE, *Education in Traditional China*, *a History*, 294.

[219] Benjamin A. Elman, *Civil Service Examinations and Meritocracy in Late Imperial China,* 15.

aminations in 1313 by the Yuan. In the case of *The Great Learning*, ZHU Xi modified parts of the text believing that some of it contained various commentaries by the ancients which did not truly reflect Confucius' teachings. He then created additional sections, with respect to the text, by composing a section that dealt with *gewu*, or the study of the underlying principles of objective, material things (*wu*), a concept which had become synonymous with western natural science by the late Qing. In effect, his modifications became widely accepted, surpassing the *Five Classics*, as the traditional canon.[220]

Toward the end of the Southern Song, Daoist orthodoxy and imperial politics were at odds because the literati, associated with *Daoxue*, more steadily began to represent the values of moral cultivation to society, and less so the emperor. In 1197, *Daoxue* was considered heterodox because the emperor perceived the literati as gaining too much autonomy, which was thought to threaten his legitimacy if society interpreted the literati as sharing power with the throne. As a result, ZHU Xi was placed under house arrest until his death. However, ZHU Xi's downfall may have had more to do than just with his *Daoxue* teachings and new pedagogical traditions. Hilde De Weerdt, a professor of imperial Chinese intellectual and political history at Leiden University, highlights ZHU Xi's manifesto on the educational reform of the civil service examinations, known as his "Private Opinion," written in 1195. Even though ZHU Xi used the press to promote moral conduct as the main criteria for selecting imperial officials in other writings such as in his commentaries, he did not allow "Private Opinion" to be published. In the eleventh and twelfth centuries, private discussions about affairs of the state held outside the imperial court connoted partisanship and factionalism, carrying political overtones. In his "Private Opinion," ZHU Xi

[220] Thomas H.C. LEE, *Education in Traditional China*, *a History*, 295–297.

outlined nine structural items calling for reform of the rhetoric and writing components of the examinations, and the abolition of lyric poetry as main items, because he regarded formulaic writing "empty talk" similar to "children's games"—literary exercises that did not allow a student to express moral intent. In ZHU Xi's view, simple memorization of words, characters and sentence structures, expressed in writing, prevented the discovery of underlying patterns in texts and the original worthiness of the sages. Although never published at the time, it was widely circulated among his peers and was known among some court officials. Published after his death, it became a foundation in examination studies in later decades, inspiring intellectuals desiring pedagogical reforms in the seventeenth and eighteenth centuries.[221] De Weerdt writes that ZHU Xi did not want to overthrow the examination system, but to work within its parameters in order to regenerate true morality, not only in society, but also in government since candidates who passed the examinations formed the bureaucracy.[222]

As woodblock printing became more widespread, the Song produced authoritative texts of the Confucian orthodox classics and commentaries, which were used for the examinations, and further legitimated the dynasty both culturally and politically. The dynasty used the new technology of printing for its own purposes to influence Chinese society, preventing the same sort of societal upheaval that occurred in Europe when printing became standard in the fifteenth and sixteenth centuries. Chaffee likens this to Needham's premise regarding the impact of printing on Europe: "For where the latter led through the vernacular Bible to the Reformation, the

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[221] Hilde De Weerdt, "Changing Minds through Examinations: Examination Critics in Late Imperial China," *Journal of the American Oriental Society*, Vol. 126, no. 3 (July–September, 2006), 367–370.

[222] Ibid., 375.

former led through the classics to the examinations."[223] The extent of the literati in China grew in response to the changes occurring in society, and the literati were strengthened by the availability and inexpensiveness of printed texts needed for examination study. As printing spread throughout the empire within the context of civil service examinations, more empire-wide schools were established outside of the capital area, extending to prefectures and distant counties, allowing more examinees to qualify. Despite the coming upheavals during the Yuan and the early years of the Ming, the classical canon remained fully operational, augmenting the civil service examinations and also the literati.

Although the Mongolians had ruled northern territories in China for decades and fought the Song for over fifty years prior to its official proclamation as the Yuan dynasty in 1271 by the Kublai Khan, Needham calls the meeting of the nomadic Mongols with the Chinese, who had a highly developed agricultural system, one of the greatest clashes in civilization. In confronting the civilization of the Han Chinese and how to make use of its land and labor, an early administrator under the Kublai Khan, YEH-LU Chu-tsai (*YELU Chucai*), also helped organize the beginnings of the civil service examinations under the Mongols. The Mongolians understood the significance of the civil service examinations for the Chinese from the Jurchen Jins, and in 1238, held an examination where over 4,000 candidates passed. Having later suspended the examinations, it took over 70 years before the dynasty officially recognized the examination system as a recruitment tool and in 1314, examinations were held after a prolonged redrafting of how the examinations could be organized and regulated and then were held every three years.[224] The Yuan

[223] Quoted in John W. Chaffee, *The Thorny Gates of Learning in Sung China,* 15.

[224] Thomas H. C. LEE, *Education in Traditional China*, *a History*, 154–155.

recruited Chinese scholars into its bureaucracy, but the highest posts were appointed to non-Chinese. Although the Yuan is considered a dynasty that was most tolerant of all religions, Daoism suffered under the Yuan with many Daosist books having been burned in both 1258 and 1281, possibly as a reaction to Daoists occupying Tibetan-Lamaist Buddhist temples (the most practiced religion during the Yuan), and was essentially driven underground, gaining the character of cult status associated with the struggle against domination by foreigners.[225] During the Yuan regime, fifteen metropolitan exams were held and an average of only twenty-one palace-level degrees were granted each year between 1315 and 1368, compared to 124 per annum under the previous Song. With less palace-level degree holders, educated scholars were prevented from securing official positions and turned to careers in medicine and the arts. Despite the fact that subjects in medicine, law and astronomy were officially withdrawn from the examination curriculum, the technical fields remained intact, but most training for these specialties occurred among commoner clerks, official aids, and Muslims and Europeans who staffed the local offices of bureaucrats, or *yamens,* during the Ming and the Qing.[226] Demoting the technical fields to the ranks of the non-literati ensured dynastic control over the examination curriculum and, moreover, control of who was allowed official positions close to the court where order and conformity could be ensured.

The Ming dynasty has generally been described as a stable period that was administered by an effective government. Yet, the early years of the dynasty were somewhat tumultuous at least in regard to the civil service examinations. When the Ming dynasty officially replaced the

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225 Joseph Needham, *SCC*, Vol. 1, part 6, 140–142.

226 Benjamin A. Elman, *Civil Service Examinations and Meritocracy in Late Imperial China,* 15–16.

Yuan, plans were announced to once again fully involve the literati for imperial service using various models of *Daoxue* to test candidates for office. In 1368, the Ming's first emperor, ZHU Yuanzhang, sought methods of his own to recruit local scholars in proximity to the city of Jianking (currently Nanjing), which was central to his legitimacy. According to Elman, ZHU Yuanzhang officially acknowledged that education was the prerequisite of an ideal dynasty which would in turn edify civilian needs and help society develop moral customs, reflecting ancient Confucian values. Daoism remained widespread, but the Cheng-Zhu school of Neo-Confucian philosophy became the dynasty's orthodoxy and was transmitted to the civil service examinations throughout the empire. It differed from ZHU Xi's principle because it denied the fusing of the investigation of all things with Confucian ideology, believing that the world of matter and the external world were separate since many observations were considered obvious to a perceptive mind and did not require investigation—nor did investigation lead to a morally cultivated mind.[227] The literati viewed themselves through the lens of Cheng-Zhu learning in general, but perceived themselves as the possessors of proper Daoist thought, not necessarily the emperor. From 1371–1384, Emperor Yuanzhang struggled with his classical advisers, who favored literati-centered learning over the emperor's terms, and put tens of thousands of officials to death in order to ensure that orthodox Daoism was the dominant philosophy of the court rather than the views held by the literati.[228] No longer would the literati be valorized—with the new emperor believing that power and knowledge descended from the top and not the reverse. These policy changes not only resulted in a diminished number of candidates who passed the Ming provincial

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[227] Thomas H. C. LEE, *Education in Traditional China, a History*, 328–329.

[228] Benjamin A. Elman, *Civil Service Examinations and Meritocracy in Late Imperial China,* 19.

examinations, but also more regimentation in the curriculum. For example, candidates were required to avoid Buddhist and Daoist vocabulary and colloquial phrases. In addition, poetry was completely removed form the examinations between 1371–1756. By the late Ming, of the nearly 50,000 candidates competing empire-wide in the provincial examinations, only 2.6 per cent succeeded in passing. As competition grew more intense, failed examinees privately turned to natural studies, attained knowledge of basic mathematics for tax-related occupations, and engaged in medical occupations which often debated "hot" and "cold" therapies regarding measles and smallpox epidemics in order to maintain a livelihood.[229] On one hand, the rigor of the examinations and the failure rates contributed to the study of the natural sciences, at least in terms of candidates' attempt to survive both intellectually and economically, which suggests a similarity to what European natural scientists did outside of a university setting in their pursuing natural studies, but primarily indicates that pursuing natural studies was still secondary to passing the examinations. Examination culture did not promote the intellectual impetus needed to observe, experiment and collect data of the physical world. The intensity of the examination curriculum illustrates how limiting the examination process was in influencing the study of nature outside of the traditional framework of a classical education.

According to Elman, government officials during the latter part of the Ming, however, did allow some variety in the examination curriculum. He argues that in late imperial China, natural sciences, along with studies in horsemanship, archery, law and music, were represented in the civil service examinations at the provincial and metropolitan levels, in order to include "local

[229] Benjamin A. Elman, "Unintended Consequences of Classical Literacies for the Early Modern Chinese Civil Examinations," 199–200.

knowledge," which represented the intellectual trends of the period. Elman claims the examination system should be analyzed in the context of cultural history and not just through an educational or political lens. He notes a common misperception among scholars that studies in the natural sciences had eroded after the Song and the Yuan up until the arrival of the Jesuits in the sixteenth century, quoting Matteo Ricci's belief that the Chinese had made considerable progress in arithmetic and geometry, but that the "teaching of these branches of learning" was more or less "labored in confusion." Examination records indicate that calendrical studies and mathematics were deemed important in certain dynasties, especially the Ming, before the arrival of the Jesuits. He reiterates Nathan Sivin's argument that the Jesuits misrepresented their scientific knowledge to the Chinese while advancing papal objectives from Europe—diminishing the success of transmitting European science to China. From this point of view, the Jesuits did not lift Chinese scholars out of their astronomical backwardness by illustrating European astronomy. Rather, Chinese scholars reassessed their own astronomical history and integrated it with what the Jesuits had shared.[230] To Elman, the examination system did not negatively affect the development of science because the exams also tested candidates' knowledge of astronomy, calendrical methods, and other aspects of the natural world in addition to the Confucian classics.[231] For example, Elman notes a policy question from a 1525 provincial examination where candidates were asked to elaborate on how the ancient kings used the calendar to institute order throughout the empire. Expanding on this topic, the examiners then asked candidates to explain the rationale

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[230] Benjamin A. Elman, *A Cultural History of Civil Examinations in Late Imperial China*, 461–462.

[231] Ibid., 465.

of using the Triple Concordance System[232] to predict celestial events during the Han, Tang and the Song. In addition, candidates were asked why the calendar had to be frequently revised, why extra lunar months had to be inserted when calculating minor lunar discrepancies, and why this system, used for at least two centuries, did not require any major revisions. In correctly answering these questions, candidates needed knowledge not only of history, but also an adequate technical comprehension of mathematical astronomy.[233] In short, one could conclude that examinees were aware of contemporary mathematics used for astronomical calculations, but were also aware that the calendar at this time contained errors. Two approaches, with which candidates used to reply, was that the Han, Tang and the Song did not have enough information, and that more accurate instruments were needed in reforming the calendar. Rather than having technical manuals upon which to rely, they relied on dynastic histories as sources for their answers, which illustrated their awareness of how essential the calendar was in political life, and how difficult it was in maintaining the accuracy of the official calendar.[234] In as much that an advanced knowledge of the history of mathematical astronomy was needed to succeed in passing the civil service examinations during the Ming, to conclude that Ming scholars were headed in the same direction regarding the development of science as their European counterparts would be misleading. But, what is remarkable, is that scholars were able to appreciate enough history of astronomy in order

[232] The Triple Concordance System was an astronomical computational method used since the fourth century C.E. to predict both solar and lunar eclipses and served to determine the calendar, and important dates and events in the dynasties. Predictions relied on calculating mean periods of both the Sun and the Moon to predict the velocity of the Moon, but used ambiguous date estimates to predict exact times of eclipses.

[233] Ibid., 468.

[234] Ibid., 472.

to translate their knowledge into acceptable answers that reflected the politics of the dynasty in order to pass the examinations. Yet, bound by the current dynastic orthodoxy, both socially and educationally, most examination candidates did not study beyond the classical canon to acquire knowledge based on their own observations or experiments and thus little advancement was made toward science.

Another limitation regarding advancement in mathematics and astronomy in the Ming and Qing courts was the Chinese hereditary family networks that spanned generations in the Bureau of Astronomy. In his dissertation, Ping-Ying CHANG discusses the mandate by the Ming emperor, Hongwu, in 1373, that families which had positions in the Bureau were forced to remain as imperial astronomers because mathematics was considered a special skill or type of knowledge that was passed on to their descendants. In effect, they could never leave the Bureau and if they attempted to do so, they would be banished to the South Sea per the decree of the emperor. In 1519, the Ming court began to regulate the Bureau of Astronomy by holding examinations among officials to check the progress of their studies, which were administered by the Ministry of Rites. According to CHANG's research, students and their teachers would be punished if no progress was made.[235] By confining familial lines, which specialized in mathematics to the Bureau, there was little opportunity for those with no hereditary privilege to enter the profession of imperial astronomers, limiting the recruitment of new talent that could have contributed to new scholarship in mathematics and astronomy. In the early days of the Qing as well, there were restricted regional quotas in the Lower Yangzi districts due to the overriding success

[235] Ping-Ying CHANG, "Chinese Hereditary Mathematician Families of the Astronomical Bureau, 1620–1850" (Ph.D. dissertation, City University of New York (CUNY), The Graduate Center, 2015), 39–40.

of candidates passing the examinations in this area of the empire, which meant advancement to official positions was unachievable. As the population steadily increased, the quota system did not keep pace and in the seventeenth and eighteenth centuries. There were roughly 500,000 men who passed the local examinations, but they were prevented from going further in the process even though they were qualified to continue, being forced to take other forms of employment as secretaries to officials, tutors for the wealthy and academy teachers. By 1800, only *jinshi* candidates could expect official positions, but this often took several years of waiting before a position became open. After 1820 and again after the Taiping Rebellion, the quotas were modified when the dynasty realized they needed more educated men to fill positions.[236]

As the dynasties transitioned, the Jesuits continued to work on calendar reform, and were largely in charge of the Bureau of Astronomy, where Jesuit Johann Adam Schall was one of the first Catholic missionaries to hold the office of imperial astronomer which he held until 1664. Muslim astronomers had been part of the Bureau since the Yuan dynasty, when the Bureau was under Mongol control. Under the Ming, they specialized in calculating planetary conjunctions and eclipses, but their methods were eventually discredited after WU Mingxuan, an official who helped lead the Muslim Section and a descendant of one of the astronomers brought in by the Mongols, improperly accused Schall of making faulty predictions that were later found to be untrue. As a result, the Muslim section of the Bureau was shut down with the Jesuits gaining more influence, and WU Mingxuan lost his status in the Bureau.[237] However, not all members of the

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[236] Benjamin A. Elman, *From Philosophy to Philology: Intellectual and Social Aspects of Change in Late Imperial China*, 167–168.

[237] Catherine Jami, *The Emperors New Mathematics: Western Learning and Imperial Authority During the Kangxi Reign (1662–1722)* (Oxford, UK: Oxford University Press, 2012), 38–41.

Bureau welcomed Western methods, which had become nearly compulsory for admittance. Schall's recruitment of officials for the Bureau did not always include the heirs of hereditary mathematician families, who had devoted years of study to the Muslim or the Triple Concordance System. Schall increasingly gained enemies, and was accused of miscalculating divinatory theories when advising the emperor. In 1664, he and his colleagues were arrested and YANG Guangxian (1597–1669), a staunch advocate of the Triple Concordance System, became the new director of the Bureau, but was dismissed in 1669 for incompetency along with many other officials.[238] To YANG, the Western method was heterodox and akin to to setting up a Western religious sect in China.[239] In 1665, western astronomical methods were dismissed by the Kangxi emperor, favoring the return of the Triple Concordance System, until 1668. Eventually, the Bureau was reorganized and the disputes over what system of calendar calculation should be used again leaned toward the Jesuits, but the ancient systems were not fully abolished. By 1711, there were suspicions brewing that the Jesuits had covered up mistakes in calculating the summer solstice, but later that year, they correctly predicted the winter solstice, which satisfied the emperor at least temporarily. In 1713, the emperor ordered the Ministry of Rites to hold special examinations to recruit new mathematicians into the court, which were equal in status to the civil service examinations.[240] Notwithstanding, the Jesuits remained in charge until 1826 when they lost their

[238] Ping-Ying CHANG "Chinese Hereditary Mathematician Families of the Astronomical Bureau, 1620–1850," 72–75.

[239] Catherine Jami, *The Emperor's New Mathematics: Western Learning and Imperial Authority During the Kangxi Reign (1662–1722)*, 49.

[240] Ping-Ying CHANG "Chinese Hereditary Mathematician Families of the Astronomical Bureau, 1620–1850," 110–112.

status in the Qing court, which resulted in their complete withdrawal from the Bureau of Astronomy.

By 1715, considering the upheavals caused by the calendar disputes, the Kangxi emperor banned all questions pertaining to the calendar or astronomy if they were related to the Jesuits methods because the questions were thought to have delegitimated Qing authority.[241] *Dauxue* methods and pre-Song aspects of the civil examinations were restored and a literary focus ensued until the Kangxi emperor's successor, Yongzheng, sought reforms. The new emperor wanted to de-emphasize the 8-legged essays held at the first level of the examinations because they did not stress practical issues or important questions regarding statecraft. However, instead of true reform, he added another level to the examination system, which tested the top-ranked palace degree holders' entry to the Hanlin Academy, by again adding a poetry question, which earlier had been eliminated under the Yuan. This was fully re-instituted in 1757 at the prefectural and metropolitan levels.[242] Discontent followed and debates occurred on whether the examinations appropriately tested candidates' ability to hold public office. Throughout the 1750s, the QIANLONG emperor encouraged practical examination questions about literary matters, but poetry remained a measure of literati talent. What drove the popularity of poetry in the examinations was the link between rules for rhyming in poetry and the growing field of phonology—the precursor to evidential research that became popular later in the century—and the realization philologically of how important poetry was for the reconstruction of ancient writing dating back to the

[241] Ibid., 42.

[242] Benjamin A. Elman, *Civil Examinations and Meritocracy in Late Imperial China*, 289.

Han.[243] Steps were taken to require more specialization in the classics and passing became even more difficult, and by 1787, *Daoxue* examination methods increasingly became controversial. In 1796, JI Yun (*JI Xiaolan*), an influential scholar from Hebei Province, who helped supervise the civil examinations, wrote that neither Han nor Song Learning could stand alone. Han scholars traced the origins of writing and texts by analyzing etymology and how it was connected to the intent of the ancients while the Song school debated subtle meanings and textual similarities and differences, which JI Yun believed prevented confusion when reading the *Classics* with other contending theories. He believed that Song Learning was a guide for classical meanings and principles, and that Han Learning should supplement Song learning to "prevent the theoretical constructions of Song Learning from getting out of hand." Changzhou scholars, however, felt there should be a more comprehensive vision of scholarship that went beyond textual scrutiny in evidential scholarship, believing that the moral principles in Confucius' *Spring and Autumn Annals* should be stressed.[244] Synthesizing both Song and Han Learning remained widespread, but as the nineteenth century approached, scholar-officials throughout the empire suggested new policy questions regarding statecraft and argued that the examinations did little to solve the social and political problems facing the dynasty. *Kaozheng* scholarship was beginning to be seen as apolitical and too "bookish" to address dynastic problems.[245] Yet, by the 1820s, the Daoguang court made little progress in practical reforms on the civil examinations.[246] The rise of New Text

[243] Ibid., 297.

[244] Benjamin A. Elman, *From Philosophy to Philology: Intellectual and Social Aspects of Change in Late Imperial China,* 271–272.

[245] Ibid., 273.

[246] Benjamin A. Elman, *Civil Examinations and Meritocracy in Late Imperial China,* 301–302.

Studies several years later, based on the revival of Confucian classics from the Han, offered a minor solution. Elman calls New Text classicism the outgrowth of two centuries of Qing *Kaozheng* scholarship where intellectuals painstakingly researched and collected philological evidence. Although scholars devoted to New Text studies rallied against both Song-Ming *Dauxue* and precise textual scholarship, calling them sterile and divisive, New Text studies were also considered reformist because they provided a philosophical rationale for statecraft studies, or *Gongyang*. WEI Yuan, a scholar living in Yangzhou in 1831, wanted to eliminate all philological studies unless they pertained to statecraft and self-cultivation which supported a moral-social impetus in reviving Qing society. To WEI Yuan, the former style of Han learning led talented men down a path of uselessness, of little service to the dynasty.[247]

According to some historians, the Qing dynasty took over the Ming form of government, maintained it, did little to upset the economy, and oversaw repairs and extensions of public works systems. It also crushed any uprisings stemming from the south and southwest of China, and the empire was able to recover from decades of previous warfare. Allowing sections of the country to be developed agriculturally, new commerce enterprises and international trade with Europe in tea, silk, porcelain and decorative paper products rose, as did the the population, which steadily increased from approximately 64,000,000 in 1578 to over 300,000,000 in the 1850s. China acquired new varieties of agricultural products from the Americas and Europe such as corn, peanuts, sorghum, potatoes and new varieties of beans—all which could be cultivated in soil of poor quality which helped feed a growing population. To the detriment of the empire, the

[247] Benjamin Elman, *From Philosophy to Philology: Intellectual and Social Aspects of Change in Late Imperial China,* 278–279.

poppy plant, already known in China as early as 1500, was more heavily imported into China from India via Macao by the Portuguese in the late seventeenth century, mixing it with tobacco making it more easily consumed. The English, among others, comprehended the impact opium would have on monetary profits and eagerly promoted its sale. Although the Qing had banned opium in 1800, the trade continued illicitly, and the Chinese government apprehended and burned significant caches of opium, leading to the first Opium War with the English in 1840, who insisted there should be no trade restrictions. In addition, the English demanded that more ports be open for trade, and exploitation of the Chinese people steadily continued. Rightly, unrest grew among the Chinese, in both urban and rural settings, and major rebellions were frequent with the Taiping Rebellion (1850–1864) being one of the most serious.[248] Interestingly, a bereft-of-hope literati, who had earlier pleaded for reforms in the civil service examinations to include statecraft policy questions that would be of practical use to the dynasty, HONG Xiuquan, led the Rebellion, wanting the Qing government to be overthrown and the Chinese people to convert to the Taiping brand of Christianity. Meanwhile, the literati (non-Taiping) further attested to the administrative incompetency of the dynasty, and local and provincial examinations halted. The Taiping rebels made Nanjing their capital where metropolitan examinations were held. When official Yangzi delta province examinations ceased in 1859, the Jiangsu examinations were moved to unaffected areas. Worthy of note is that most of the top leaders of the Taiping, including HONG Xiuquan, had failed the traditional Qing examinations. As a result, they set up their own system, understanding the examinations' role in legitimating their cause, and eliminating any classical Chinese texts that were contrary to the Taiping's beliefs. Instead, they instituted

[248] L. Carrington Goodrich, *A Short History of the Chinese People*, 218–225.

Chinese translated versions of the Old and New Testaments, and writings devoted to Hong himself, emulating earlier uses of *Daoxue* and the *Five Classics* upheld by the Ming and the Qing. As opposed to asking what is the true way, however, HONG, who oversaw the examination questions, asked "Is the true way the same as the worldly way?" In 1854, in Hebei alone, 80 per cent of the candidates passed compared to the 20 per cent passing rates under the official Qing administration. HONG realized that the more men who passed could serve as loyal officials under his administration in as much that with fewer failed candidates, there were less who could undermine him.[249] To HONG, as he advocated earlier in wanting to reform the examinations, content was more relevant than form. Yet, candidates were still expected to write essays in the 8-legged format, but within a biblical context, and candidates were still expected to answer poetry questions on style-regulated verse which was more or less consistent with the Ming and Qing testing systems. In 1859, political reforms commenced by another important leader in the movement, HONG Rengan, a cousin of HONG Xiuquan. Desiring to follow the Qing system even more closely, the *Analects* and *Mencius* became the foundations of examination essays. Nevertheless, the Taiping were eliminated in 1864.[250] Due to the impact of the Taiping Rebellion, many of the books—including woodblocks the literati labored to save and revive via *Kaozheng* scholarship—were destroyed. In addition to the destruction of revered texts, schools, public and private libraries, and academies perished. Above all, many lives were lost, with some estimates concluding that over 7,000,000 people died.[251] The fact that the Taiping, who wanted to overthrow the

[249] Benjamin A. Elman, *Civil Examinations and Meritocracy in Late Imperial China,* 302–304.

[250] Ibid., 305.

[251] Benjamin A. Elman, *From Philosophy to Philology: Intellectual and Social Aspects of Change in Late Imperial China,* 288–289.

Qing government, and willingly recognized the importance of the examinations, is paramount. This not only legitimated their cause, but it also legitimated successful candidates, and suggests even further how relevant the civil service examinations were throughout the Chinese dynasties in consolidating power and maintaining order, but also how culturally ingrained the examinations were among the population. The destruction of ancient texts and libraries does little to showcase the Taiping cause, but it does illustrate how class and philosophical distinctions between the literati and the non-literati no longer represented Chinese society, both socially and culturally.

As the Qing attempted to reconsolidate its power after the Taiping Rebellion, the dynasty was nevertheless weakened and scholar officials faced reshaping the examinations in order to better serve the dynasty. They sought reforms that included modern Western and Japanese models of education and included subjects in practical training and commerce. They also built arsenals and shipyards. However, this did not bridge the gap between the literati and the non-literati. As Western influences steadily infiltrated China, including proselytizing missionaries and industrialists, the Chinese government, and many of its people, opposed contact with non-Chinese and distrusted foreign traders. Relations remained strained; yet, the dynasty opted to adopt particular elements of Western technology and international law, and set up foreign language schools. Adopting Western practices, it was difficult to preserve Chinese culture, and many of the Confucian values they desired to maintain were instead undermined.[252] At the turn of the twentieth century, what was old and what was novel in China were expected to synthesize, but the effects of the interpenetration by Western powers were irreversible. Young men were trained in Western military tactics, and modern communication systems were introduced along with Western scien-

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[252] Jonathan D. Spence, *The Search for Modern China*, 140.

tific textbooks. For families of the upper classes, traditional education remained and the Confucian classics were studied in hopes that candidates would still reach the *jinshi* level.[253] The Chinese of the lower classes gained more wealth due to trade in agricultural goods and were exposed to Western popular literature with tempting advertisements to buy commodities. Although more Western influence continued to exert itself in China, most of the population did not reap the economic benefits and began to feel resentment toward foreigners, the missionaries, and their own countrymen who had converted to Christianity. In 1898, the Boxers United in Righteousness forcefully emerged in northwest Shandong and local peasants were recruited, who, out of animosity, destroyed and stole property. Several Christian converts on the Shandong-Hebei border were murdered, often because of the special privileges the converts had received. Alarmed by these events, Westerners demanded that the Qing suppress the Boxers, but the Boxers often responded with slogans such as "Revive the Qing, destroy the foreign," which soon spread, encouraging significant disenfranchised others to join the Boxers in order to fight the "polluted" foreigners. In June of 1900, the Empress Dowager Cixi issued a "declaration of war" against foreigners, who were believed to have infringed upon the empire. By August of the same year, over 20,00 troops from Japan, Russia, Britain, the United States and France, defeated the Boxers at Peking (Beijing), but the court sought refuge in Xi'an and a treaty, known as the Boxer Protocol, was signed in 1901, forcing China to pay the allied powers huge indemnities until 1940 when their debts were finally paid.[254] Despite the monetary losses inflicted on U.S. citizens and businesses during the Boxer Rebellions, in 1908, the American government returned at least two-

[253] Ibid., 224.

[254] Ibid., 231–235.

fifths, or about $11,000,000, of its indemnity back to the Chinese government with the stipulation that it be used so that Chinese students could receive scholarships to study at U.S. universities. Tsinghua University (*Qinghua Daxue*) was also established in Peking as a preparatory school for Chinese students before studying in the U.S, where over 1200 students were educated between 1909 and 1929. In 1924, a second remission was made and entrusted to the China Foundation, a joint Chinese-American committee created to promote cultural and educational exchanges.[255] Today, Tsinghua University is considered one of the top academic institutions in China and Asia for study and research in science, medicine and technology.

In 1903, ZHAN Zhidong, a Huguang province governor-general, who helped negotiate the Boxer Protocol, also encouraged reform of the civil service examinations, modeling a system after the Japanese, whose schools were integrated with examination academies. He also advocated that all military examinations be abolished and urged sending students abroad to study. Establishing schools was a formidable task and those qualifying for and passing the civil service examinations still superseded those successfully graduating from schools for official posts because the mindset still existed that the best path to an official position was via the civil service examinations. Gradually, the 8-legged essay format was slowly abandoned and candidates were expected to answer examination questions combining Western and Chinese knowledge. By 1904, a Committee on Education was established in order to create reforms with schools replacing the examinations. After the Russo-Japanese War of 1904–1905, the political climate in China became dire and the examination system was blamed for the calamities of the empire. By 1906, the

[255] Michael H. Hunt, "The American Remission of the Boxer Indemnity," *The Journal of Asian Studies*, Vol. 31, no 3 (May, 1972), 539–540.

quotas for examinations were reduced by one-third in order that the empire could continue to adopt the ideals of universal education. It was eventually admitted that the examinations prevented true educational reform in China and in 1912, the civil examinations were officially abolished.[256]

In response to the Needham Question, both Chaffee and Elman agree that the imperial examinations included policy questions relating to science, however, it is insufficient to conclude that science was promoted or held in the same regard as it was in Europe. Paul Cressey compares a successful palace candidate, or *jinshi*, to an Olympian athlete in ancient Greece, with the honors received by the former more distinguished.[257] The prestige attached even to being associated with the civil service examinations was considerable, whereas the pursuit of the natural sciences was often associated with the commoner, or the non-literati, and in effect, was delegitimatized by the dynasties. This allowed no aspiration for scientific studies and was an impediment to attaining a scientific revolution. Both Needham and QIAN believe that China's failure to transition from premodern to modern science may be explained by its social and political structures—structures that supported and perpetuated the imperial examination system and, at the same time, were molded by it. *Keju* was a vehicle for effecting the continuance of Confucian orthodoxy often synonymous with the rejection of scientific progress. Successful scholars and philosophers functioned as government officials—many of whom had little incentive during their course of study to focus on topics that did not relate directly to the examination curriculum. Offi-

[256] Benjamin A. Elman, *Civil Examinations and Meritocracy in Late Imperial China,* 313–315.

[257] Paul Cressey, "The Influence of the Literary Examination System on the Development of Chinese Civilization," 254.

cial positions were based on classical learning bequeathed by the ancient kings, which presupposed political competence and no expertise in natural studies or technical learning.[258]

The imperial examinations were a means of imposing social control which the emperors could exert throughout the dynasties. In return for achieving such status, obedience and the continuous striving for loyalty to the dynasty was expected. As noted above, studying took years of work with all educational focus devoted to Confucian texts which championed obedience, harmony and respect for tradition and order. Individuals were recruited based on their adherence to Confucian thinking which sustained the dynasties and promoted imperial dominance. Yet, those who failed were also a part of the regime because they often became teachers to aid others in study while still promoting Confucian thinking and cultivating obedience. During the Ming dynasty, only about five per cent of all candidates throughout the empire passed the examinations at the higher levels and during the Qing, less than two per cent did so. In addition to teaching, those who failed at both the higher and lower examinations, became doctors, Buddhist or Daoist priests, legal practitioners, merchants, astronomers, mathematicians, printers and publishers, and secretaries to officials.[259] Interestingly, those who failed were still classically literate and highly educated. They were by-products of a system that failed to produce modern science similar to what was achieved in Europe, but their intellect helped sustain imperial interests and dynasties that prevailed for hundreds of years until the ultimate fall of the Qing in 1912.

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[258] Benjamin A. Elman, "From Pre-modern Chinese Natural Studies to Modern Science in China," 41.

[259] Benjamin Elman, "Unintended Consequences of Classical Literacies for the Early Modern Chinese Civil Examinations," 204–206.

CONCLUSION

It was from Joseph Needham's friendship with the visiting Chinese biochemists at Cambridge in 1937 that he first learned of the immense contributions Chinese civilization had made during the Medieval period in science and technology, which "have since flowed into the ocean of modern science."[260] Throughout his life, he composed hundreds of publications and contributed to multiple volumes of *Science and Civilisation in China,* synthesizing eastern and western knowledge, and often asserting that on many levels, China was more technologically and scientifically advanced than Europe until the onset of the Scientific Revolution in the 1500s. China's early development of paper and the printing press played a central role in the dissemination and standardization of knowledge, and it was a major factor in transforming both Chinese and European societies. Although the Chinese developed movable type printing as early as the eleventh century, using woodblocks remained their preferred method of printing until much later. During the Song, woodblock printing increased in both private and government sectors and books became more affordable. The printing press also greatly impacted the civil service examinations where wider publication of textbooks and exam-related materials were further demanded. Diversification of the kinds of books published accelerated and encouraged more communication among scholar-officials, examinees and examiners, leading to socio-political changes that might not have occurred without the development of printing.[261] Historians often compare the flourishing of printing during the Song dynasty to fifteenth-century Europe, when moveable type print-

[260] Joseph Needham, *The Grand Titration*, 200.

[261] Seung-Hwan MUN, "Printing press without out copyright: a historical analysis of printing and publishing in Song, China," 3.

ing was created and spread rapidly as well. As the population in China steadily increased, so did the number of licentiates attempting to pass the exams, and there is a strong correlation of the number of books printed in China with the number of examinees during both the Ming and Qing dynasties as noted earlier. In essence, it is thought that the printing press mandated conformity in China whereas in Europe, it helped foment individuality.

In Europe, after movable type printing was developed in 1440 by Gutenberg, manuscripts from antiquity proliferated and the awareness of various textual inaccuracies by scribes became obvious when comparing manuscripts by the same author. This led scholars of the period to compare their knowledge to ancient texts, noting errors such as Vesalius did when analyzing the illustrations of Galen, or Copernicus, who was more easily able to compare his celestial observations with Ptolemy's geocentric model of the universe in order to put forward his own theory of heliocentrism. The printing press allowed uniformity in publications and new views were rendered that often contained personal observations and experimentation, which were available both to academics and non-academics, and which broadened readership. As Elizabeth Eisenstein contends, the printing press did not cause the Scientific Revolution in Europe, but it was a crucial variable in determining how printing aided the development of modern science.[262]

With respect to the Needham Question, China, too developed a tradition of comparing ancient works, considering *kaozheng,* which gained in popularity during the Qing dynasty. Jonathan Spence concludes that *kaozheng* methodology allowed Chinese scholars to explore writings from past dynasties, which in turn encouraged new views on technology, hydraulics, cartography and ancient government treatises. In addition, scholarly projects were promoted and

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[262] Elizabeth Eisenstein, *The Printing Revolution in Early Modern Europe*, 75.

surviving Ming dynasty texts on mathematics were reprinted in order to reconstruct traditional Chinese mathematics, and at the same time, help preserve texts that were thought to be lost or destroyed.[263] However, as scholars have pointed out, printing in China was mostly a means of circulating ideas favorable to the state, and Chinese scholars were hesitant to challenge the state or ancient writings written by their predecessors.

Whereas the imperial examinations had a direct effect on the lack of development of science in China, one must ask whether the structure and the strictness of the examinations were the cause or merely a symptom of China not developing modern science. Having begun in the Sui dynasty, the imperial examinations were officially established by the Tang, and were a mechanism that helped ensure that candidates from various social backgrounds could participate in the examinations. In the Song dynasty, the examinations were greatly modified, corresponding to changes occurring in society. After the Northern Song transitioned to the Southern Song, the examinations were fully entrenched in Chinese society and the culture of the examination system blended both the elements of the Confucian classics and the ethical-philosophical discourse of *Daoxue,* where moral cultivation was thought to have positively impacted the candidates and the state itself. During the Yuan, the examinations were reorganized and there were less palace-level degrees awarded with the educated often turning to careers in technical fields in order to maintain a livelihood. After the decline of the Mongols, Chinese classical scholars during the Ming further committed to *Daoxue* interpretations as the examination orthodoxy, but very structured commentaries upon which examinees were expected to write, such as the 8-legged essay format, dominated. Intellectual capacity was enhanced, but did little to promote practical governance,

263 Jonathan D. Spence, *The Search for Modern China*, 104.

science, or modernization even though the Jesuits attempted to spread European astronomy and mathematics during this period. Internal political problems during the Ming only widened the gap between China and the West, but the civil service examinations continued to define Chinese society. The clash between classical discourse and imperial politics never quite promoted the intellectual impetus needed to develop modern science and its necessities of observing, experimenting, or collecting data from the physical world. Astronomical and calendrical studies continued to serve the emperor in order to maintain the empire according to the philosophy of governance dating back to the ancients. The Qing rulers maintained a similar form of governance as the Ming, but increased contact with foreign governments and peoples only solidified the fact that China's one-thousand year system of governance, maintained by bureaucrats who rose to their positions via the civil service examinations, no longer positively served the empire. After the Ming fell to the Manchu and foreign penetration of the region brought infringements upon the Chinese state, considering the Opium Wars and the Taiping Rebellions, the Qing eventually sought reforms regarding the examination system and began to adopt ideals of universal education that did not require the exclusive study of the Confucian classics or *Daoxue* philosophy. In due course, the civil service examinations were abolished. After the collapse of the Qing empire in 1912, China endured a difficult transition period. Its finances were in disarray; there were natural disasters, ruined agricultural enterprises and in effect, famine. The country was severely divided with many supporters of the former Qing remaining loyal, but there were mounting pressures from foreign powers to whom China was in great monetary debt. New modes of communication, industrial development and transportation emerged and the philosophy of Confucianism, which had dominated most of Chinese society, was highly contested. During this period, thousands of civilians and military personnel perished and a fragmented republic with socialist sentiments was formed. [264]

In addition to the civil service examinations, there were other inhibiting factors that prevented China from attaining Western modern science or a Scientific Revolution. Needham believed that China had no economic incentive to develop modern since because it lacked a merchant-capitalist system that was dominated by a centralized bureaucracy whose sole function was to administer the state in order to ensure its imperial power, unlike the West which acknowledged scientific knowledge and the application of technological progress as a benefit to society. Needham believed that the rise of modern science occurred simultaneously beginning with the latter part of the Renaissance, the Reformation and the rise of capitalism. Both the Merton and the Weber theses supported Needham's perspective in several ways. Max Weber linked the Protestant work ethic and the rational pursuit of economic gain to the rise of modern capitalism. In a similar vein, Robert K. Merton correlated the rise of Protestantism with the growth of early experimental science because science was a useful tool for pursuing practical activities, glorifying God as man attained dominance over and comprehended the physical world. Although Needham had read both theses, he viewed science in terms of the entire world and not just the West, believing that the development of modern science and capitalism were accompanied by Protestantism, but that other sociological factors must be considered when analyzing the inhibiting factors in China. China lacked the economic incentive for scientific development because it never developed because of its economic system and Needham saw China's early economic system as more rational than the West's, and a form of Marxism was a leading component in his evaluations.

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[264] Jonathan D. Spence, *The Search for Modern China*, 275–277.

Other factors to consider regarding the Needham Question are the differences in China's and Europe's philosophical traditions, social institutions, and the concepts of time and language. In China, Buddhism, Confucianism and Daoism marginalized the importance of studying science and mathematics—often because of the emphasis on social harmony in which it was thought that the consequences of nature were to be accepted and too complex to be comprehended—whereas the West perceived the universe from a mechanical Newtonian perspective, where nature could be explained with logic, experimentation and mathematics. In addition, the Scientific Revolution in Europe was fostered by social institutions such as the Lincean Academy and later the "invisible" college, later formalized at the Royal Society. China lacked similar institutions, which stimulated individuality and above all the study of science. Instead, China developed an educational system that focused on the content of the civil service examinations, which focused mainly on ancient classical texts, which also governed its concept of time, which China primarily viewed as being handed down from the first Yellow Emperor in an era when Chinese civilization was in its most ideal, harmonious state. Progress meant replicating the past rather than looking forward. Time was originally viewed as cyclical, and nature as rhythmic, where every organism, including man, passed through a cycle each with its own *Dao,* with little need to theorize about time and how it should be measured. The concept of linear time was subsequently balanced with the cyclical in order to accurately predict celestial events. The concept of time in the West, on the other hand, was linear and stems from the Hebraic-Christian tradition where historical events were marked with a beginning and an end. Early mathematicians and astronomers developed instruments to measure time accurately, and also to determine speed—necessary for astronomical observations, which further aided in the development of science. Likewise, scholars have speculated whether the Chinese ideographic script hindered the development of modern science although Needham rejected this claim, explaining that when China did actually begin to develop science, the same script was used. In comparing linguistic structures between Chinese and Indo-European languages, however, there is evidence that suggests that the structure of the Chinese language affects cognition because it lacks the subjunctive mode, or the ability to answer counterfactual questions, which inhibit abstract reasoning, which in turn affects the logic needed for developing science.

There are other significant viewpoints about what impeded China from developing modern science that deserve attention—namely, arguments advanced by Mark Elvin, Justin Yifu LIN and Robert Multhauf. First, in an attempt to review the Needham Question with an "outsider's objectivity," Mark Elvin, Professor Emeritus of Chinese History at Australian National University, commends many of the inspirational qualities that Needham contributed to the comparative analysis between China and the West in the *SCC*, but he also contends that some of Needham's observations are disputable because they are not error-free, often interpretive and occasionally speculative.[265] In an attempt to further advance the Needham Question, Elvin compares China's and Europe's pre-modern economies and hypothesizes that China's stagnation was partly based on failures of supply technology, which Elvin calls the "high-equilibrium trap." By the fourteenth century, China had already maximized its potential for sustained industrialization and technological advancements. Due to its citizen's desires to broaden male lineage, the population rapidly increased, yet economic conditions stagnated. The amount of land to cultivate was limit-

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[265] Mark Elvin, "Introduction" (Symposium: The Work of Joseph Needham), *Past and Present* no. 87 (1980), 20.

ed and further technological development diminished because it had already been fully exploited. Agricultural labor became less expensive while resources became more expensive. Therefore, the demand for new technology to reduce labor decreased, but so did the surplus required for maintaining industrialization. In Europe, on the other hand, the man-to-land ratio and agricultural surplus was favorable at this time, due to its hereditary feudal system, and the desire to create labor-saving technology remained a strong incentive, leading to the development of science and industrialization.[266]

Justin Yifu LIN also proposes that inhibiting factors in China can be explained by the failures of demand and supply in China, but refutes Elvin's demand-failure hypothesis, questioning whether the potential of available land, cheap labor and agricultural potential is a function of technology and whether China's "lack of inventive creativity" was actually the result of the rising man-to-land ratio.[267] Citing population statistics, LIN writes that China's population increased until 1200, but declined around 1400, recovered to its 1200 levels around 1500, reached a new peak around 1600, collapsed around 1650, but then steadily increased thereafter. Agricultural land per capita was fifty per cent higher in the fourteenth century with per capita acreage even higher in the mid-1600s, so labor-saving technology should have risen as well when the population declined if adhering to the man-to-land ratio proposed by Elvin. He states that labor shortages always occurred, especially when first crops were reaped and second crops were sowed simultaneously. Therefore, labor-saving technology was always a pressing need and China's lack

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[266] Mark Elvin, *The Pattern of the Chinese Past* (Stanford, CA: Stanford University Press, 1973), 268–298.

[267] Justin Yifu LIN, "The Needham Puzzle: Why the Industrial Revolution Did Not Originate in China," 272.

of developing technology cannot be explained according to this hypothesis.[268] In LIN's view, as long as man's material impulses remain unsatisfied, there will always be demands for new labor-saving technologies. If this does not occur, the lack of demand is a result of the failure of supply. In his response to the Needham Question, technological inventions in the pre-modern era stemmed from experience, but in modern times, they stemmed from experimentation with trial and error that coincided with science: "China fell behind the West in modern times because China did not make the shift from the experience-based process of invention to the experiment cum science-based innovation, while Europe did so through the scientific revolution in the seventeenth century."[269] To reiterate, LIN also relates China's failure to transition to modern science to the examination system because it provided little impetus for one to strive toward scientific endeavors, "especially from the mathematization of hypothesis about nature and controlled experimentation."[270] In order to advance toward modern science, one needed updated knowledge about the natural world and the universe as well as continued training and controlled experiments to build upon this knowledge, maintaining that this built-up knowledge and training was a requirement for the accumulation of "human capital" to determine what could be added to scientific knowledge via empirical observation and experiments, which is something the West achieved. The prestige attached to the civil service examinations suppressed any motivation to truly understand how or why a calamity occurred, such as a flood or an earthquake, allowing little room for the accumulation of scientific knowledge. Eschewing the orthodox curriculum to explain a nat-

[268] Ibid., 272–274.

[269] Ibid., 275–276.

[270] Ibid., 284.

ural disaster scientifically would result in disqualification and therefore a demotion in one's social and political status. Prestige and its close association with the civil service examinations supported upward mobility in Chinese society. Therefore, the advancement of science could never occur, despite China's earlier scientific achievements. The years of study required to pass the examinations, as well as the demands of being an official, and the struggles of attaining a higher rank in officialdom provided little incentive or time to acquire scientific knowledge.[271]

Last, Robert Multhauf, historian of science and a founding member of the Society for the History of Technology, evaluated the *SCC* directly after Needham's death in 1995—mainly from the viewpoint of technology, characterizing Needham as both a scientist and an historian, but also an "applied sociologist." Although Muthauf implicitly states that some of his "remarks are reluctantly made," seeing Needham as a "virtual founder of a discipline…who made a firm launching pad from which others could make 'advances' in a history that had barely existed before them," Multhauf's criticisms are not without value.[272] For example, he recounts Needham's desire to root the fundamental ideals of Chinese science in the empiricism of Daoism as an attempt at rationalization. Needham's conclusions that the Chinese sciences were descriptive, not logical and based on the practical are suspect since astronomy in China was important to the state and diurnal revolutions were accounted for using equatorial mountings and a water-driven mechanism—at least according to Su-Shu HUANG, an astro-physicist, who also reviewed that particular volume of the *SCC*.[273] Multhauf sees more technological history than the history of science

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[271] Ibid., 285.

[272] Robert Multhauf, "Joseph Needham (1990–1995)," *Technology and Culture*, Vol. 37, no. 4 (1996), 890–891.

[273] Ibid., 884.

in the *SCC*, with total page amounts that "threatened the weight-lifting power of the reader." Or, there were not enough references such as with the windmill. In Needham's attempt to merge Chinese and European science via the miniature clocks "transmitted" by the Jesuits in 1583, Needham originally deemed the clock a European invention, but later retracted this after tracing the Chinese escapement back to the eighth century. Multhauf also reconsiders many of Needham's perspectives regarding hydraulics and engineering. He contends that Needham overly applauded these Chinese innovations even though historical evidence often suggests that his facts were not error-free. In terms of the Chinese developing paper and printing, Multhauf scoffed at the lengthy volumes as he does the spirit with which Needham put forth his theories on Chinese alchemy and their later development of chemistry, not to mention his views about biology and military history. All in all, Muthauf criticized the bulk of the *SCC* and how Needham attempted to rectify history by contending that China never "lagged behind" to the extent that many historians have contended.[274]

Comparing the history of science in both China and Europe, often a great divide between the two civilizations is noted—something which Needham opposed and often gave substantial credit for technological and scientific discoveries to the Chinese. Until recently, science has been equated with Western civilization, but today this analysis is open to new areas of research, especially considering the accomplishments China has made since the middle of the twentieth century.

After the devastations of WWII, which in part Needham experienced, China officially became the People's Republic of China (PRC) in 1949, which continues today. After 1949, the

[274] Ibid., 885–890.

philosophies of science and technology in China underwent dramatic changes and were no longer disciplines considered less in stature to Confucian ideology when the civil service examinations were the main focus of higher education during the dynastic periods. The PRC needed new innovations in science and technology to advance and sustain a growing society, but instead of following leads from Western science, China at first followed the USSR and adhered to the doctrines put forth in Engels' *Dialectics of Nature,* which espoused dialectical materialist views of nature, criticizing the metaphysical. All scientists were forced to develop science and technology according to Maoist methodology, which was explained from the class perspective of the proletariat. The Theory of Relativity, genetics, Western and traditional Chinese medicine were attacked because they were considered to be the sciences of the bourgeoisie.   Degrees in higher education were based on the *Dialects of Nature* and reading this text was obligatory. In the 1950's, the Soviet model of education was introduced, which entirely restructured universities and colleges, and centered on science and technology with education in the humanities greatly reduced. After the death of MAO Zedong in 1976, it was pointed out that science and technology were "primary productive forces" and not political ideologies, whereupon communication was renewed among western scientists.[275] The period to follow implemented educational reforms, university enrollment was expanded and students were sent abroad in order to meet the demands of economic development.

At the same time, foreign experts and their investments were allowed to enter China with the goal of acquiring Western technology. To the chagrin of Chinese leaders, Western culture be-

[275] Yuanlin GUO, "The Philosophy of Science and Technology in China: Political and Ideological Influences," *Science and Education* 23 (2014), 1836–1837.

gan to spread in China as well. In the 1980's, various writings from the late Qing dynasty were republished as well as Western collections of contemporary social and natural sciences.[276] By 1989, however, the conservatives in the Communist leadership believed that Western ideas were contaminating Chinese society, especially considering the reforms in Eastern Europe and the demise of the Communist regimes there. For three years following the protests at Tiananmen Square, the government attempted to "clean up Western contamination."[277] In 1992, JIANG Zemin, China's General Secretary until 2002, reinstated economic reforms and collaboration with foreign countries. The following years saw rapid growth and in 2001, China officially engaged in the global economy by becoming a member of the World Trade Organization. By 2012, there were over 200,000 Chinese students enrolled in U.S universities.[278]

Since Needham's death in 1995, China has undergone a myriad of evolutionary societal changes that have affected its economy, as well as its scientific and technological advancements. Censorship, such as during the dynastic periods of China, still exists, but with the rise of the internet and online communication, the Chinese government has less control over printed material than in previous years. During the past few decades in China, the government has realized the needs of its society and has been open to international cooperation and the common pursuit of knowledge. With China's continuing efforts to remain less isolationist, especially in regard to its participation in the global economy, its achievements over the past few decades have astonished the world. A country once thought to be "lagging behind" currently is spending trillions of dol-

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[276] YONG Zhao, *Who's Afraid of the Big Bad Dragon?: Why China Has the Best (and Worst) Education System in the World* (Somerset, NJ: Jossey-Bass, 2014), 84–86.

[277] Ibid., 90.

[278] Ibid., 95–96.

lars in various sectors to advance clean energy initiatives, information technology and biotechnology. It is estimated that six billion dollars will be spent per year on its space program and space technology with the intention of reaching Mars by 2020.[279]

Today, there is a positive trend in Chinese science with young Chinese scientists studying abroad, sharing their knowledge with the world and vice versa. With the vast majority of these young scientists planning to return to China, there are abundant opportunities for scientific research and technological development. It is hoped that Western academic communities will support China's long odyssey into a world of greater openness and that it will also continue to promote more candor and collaboration, so that knowledge regarding new scientific and technological discoveries will positively impact our physical world. To paraphrase Needham, may advances in science and technology continue to flow from myriad sources into the ocean of modern science and be shared by all nations.

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[279] Stuart Clark, "China: the new space superpower," *The Guardian*, accessed October 4, 2016. https://www.theguardian.com/science/2016/aug/28/china-new-space-superpower-lunar-mars-missions.

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