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Joseph Needham's Research on Chinese Machines in the Cross-Cultural History of Science and Technology

ZHANG BAICHUN and TIAN MIAO

ABSTRACT: Using cross-cultural comparison, Joseph Needham composed a “connected history” of Chinese science and technology in global context, so that his *Science and Civilisation in China* (SCC) offered a refreshing view of science and technology to readers. In the SCC's subvolume on mechanical engineering (vol. 4, part 2), for example, the authors identified many inventions in premodern China, including the efficient harness, the gimbal, and the waterwheel linkwork escapement. Needham further tried to verify the possible origin and transregional dissemination (including stimulus diffusion) of such inventions as the astronomical clockwork and the interconversion of rotary and rectilinear motion in Eurasia. Although it was difficult to make satisfying arguments about the impact of Chinese knowledge on any European invention, Needham's methodologies, and even his enlightening speculations, are of real significance for present and future scholarship.

Introduction

Joseph Needham (1900–1995) spent almost half a lifetime researching the Chinese tradition of knowledge and heading up the creation of the seminal book series *Science and Civilisation in China* (SCC), which remains the most comprehensive work on the history of science and technology in China available in non-Chinese languages. Contrary to Eurocentric practices of his time, Needham pioneered the integration of Chinese science and technology as a sample of non-Western traditions into the his-

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tory of world civilization.¹ He and his collaborators made comparative studies of knowledge, and connected histories from China to other places, so that they could construct “bigger” histories of technology from transregional or even global perspectives. In this sense, then, the “old-fashioned” questions and methodologies Needham focuses on are of real significance for contemporary readers. They remain exciting areas to develop and thus deserve further analysis.

FORUM

Apart from the scholars who worked with Needham, Chinese historians made their own significant contributions to comprehensive research on the same subject. In the 1950s the Chinese Academy of Sciences established the Research Department on the History of Natural Sciences (the predecessor of the Institute for the History of Natural Sciences), which was committed to studying the history of science and technology in premodern China. However, as a result of political movements and other factors, there were long delays before Chinese historians of science and technology could realize the aspiration of composing a series on the history of science and technology in the premodern era.² It was not until 1990 that, under the sponsorship of the Chinese Academy of Sciences, the Institute for the History of Natural Sciences began to organize Chinese historians to write *中国科学技术史* (*Zhongguo kexue jishushi*) [The history of science and technology in premodern China] in Chinese.³ As of 2010, twenty-six volumes of this series had been published. This set of books fully utilizes indigenous sources and archaeological materials, and conducts systematic verification and elucidation of disciplinary history, far exceeding SCC in these regards. Nevertheless, Chinese scholars are still outstripped by Joseph Needham in the overall understanding of the transregional dissemination of science and technology and comparative studies.⁴

This article neither intends to comprehensively evaluate SCC nor attempt to discuss the so-called Needham Question. The primary purpose is to provide a discussion of Needham’s methodologies in studying the history of Chinese science and technology, with his subvolume on mechanical engineering (SCC 4.2) as an example, and focusing on Needham’s cross-cultural perspective.

1. Gregory Blue, “Science(s), Civilization(s), Historie(s): A Continuing Dialogue with Joseph Needham,” in *Situating the History of Science: Dialogues with Joseph Needham*, ed. S. Irfan Habib and Dhruv Raina (New Delhi, 1999), 29–72.

2. Baichun Zhang 张柏春, “Bawo shidai maibo, kaituo xueshu xinjing: Zhongguo kexueyuan ziran kexueshi yanjiusuo 60 nian” 把握时代脉搏, 开拓学术新境: 中国科学院自然科学史研究所60年 [Sixty years of development of the institute for the history of natural sciences, Chinese Academy of Sciences: 1957–2016], *Ziran kexueshi yanjiu* 自然科学史研究 [Studies in the history of natural sciences], 2017, 36:143–51.

3. Jiayi Lu 卢嘉锡, ed., *Zhongguo kexue jishushi* 中国科学技术史 [History of science and technology in premodern China] (Beijing, 1998–2010).

4. Zezong Xi 席泽宗, “Zhongguo kejishi yanjiu de huigu yu qianzhan” 中国科技史研究的回顾与前瞻 [Retrospect and prospect of studies on the history of science and

Identification of Inventions in Premodern China through Comparison

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In the first volume of SCC (1954), Needham alphabetically listed the attainments of science and technology in premodern China.⁵ Mechanical inventions constituted most of them, including the square-pallet chain-pump, metallurgical blowing engines, the rotary winnowing machine, the piston-bellow, the draw-loom, silk-handling machinery, the wheelbarrow, the sailing carriage, the edge-runner mill, the wagon-mill, the efficient harness, the helicopter top, and the “Cardan” suspension. Certain devices in the list were noted in *Zhongguo jixie gongcheng shiliao* 中國機械工程史料 [Materials for the history of mechanical engineering in China] compiled by Liu Hsien-Chou 劉仙洲 (1890–1975) in 1935.

Prior to the subvolume on mechanical engineering of SCC (1965), the Chinese historian of technology Liu Hsien-Chou published the first edition of his *Zhongguo jixie gongcheng famingshi* 中國機械工程發明史 [History of inventions in Chinese mechanical engineering, 1962]. By referring to the categories of modern mechanical engineering, Liu identified premodern technologies but rarely made comparisons between them and machinery in other civilizations. Unlike Liu, by drawing comparisons Needham distinguished inventions in the history of premodern China and observed that China served as the inventor or contributor of efficient harness, “Cardan” suspension, and helicopter top. For some inventions, Needham might not be the earliest researcher to study the material, but he offered unique contributions to their identification. For instance, he stated that the water-powered armillary sphere and celestial globe tower (astronomical tower for short) was equipped with the earliest escapement clocks.⁶

A typical example can be found in the identification of the gimbal (or the gimbal suspension). Needham first introduced the European gimbal suspension in reverse chronological order and remarked that it was also designated as the “Cardan” suspension “because it was described by Jerome Cardan in his *De Subtilitate* in 1550.”⁷ During the Renaissance, this device was employed for the mounting of the mariner’s compass, in the thirteenth century, for hand-stoves, and, in the Islamic world, for incense-burners. Needham traced this device to the “ring-suspension,” which was mentioned in the *Pneumatica* of Philo(n) of Byzantium (ca. 220 BCE),

technology in China], in *Kexueshi bajiang* 科學史八講 [Eight lectures on the history of science] (Taipei, 1994), 19–43.

5. Joseph Needham, *Science and Civilisation in China* (Cambridge, 1954), 1:242.

6. Joseph Needham, Wang Ling 王鈴, and D. J. Price, “Zhongguo de tianwen-zhong” 中國的天文鐘 [Chinese astronomical clockwork], translated by Xi Zezhong 席澤宗, *Kexue tongbao* 科學通報 [Science bulletin] (June 1956): 100–101; Joseph Needham, Wang Ling 王鈴, and D. J. Price, “Chinese Astronomical Clockwork,” *Nature*, 1956, 177:600–602.

7. Joseph Needham, *Science and Civilisation in China* (Cambridge, 1965), 4.2:229.

which could keep an ink bottle pointed mouth upward. Nonetheless, the historian of science G. Sarton cautions that this claim may be “an interpolation of later Arabic compilers.” Needham endorsed Sarton’s point of view and suspected the justifiability of the descriptions made by Philon.⁸

Needham then shifted his attention to China. He made note of two Tibetan brass globe lamps containing gimbals, two incense-burners dating from the Tang period (618–907 CE) that were exhibited at the Victoria and Albert Museum, and points to the records of incense-burners in chapter seven of *Hsi Ching Tsa Chi* 西京雜記 [Miscellaneous records of the Western capital] in the second century CE:

The *Hsi Ching Tsa Chi* says: In Chhang-an there was a very clever mechanic named Ting Huan . . . [who] also made a “Perfume Burner for use among Cushions,” otherwise known as the “Bedclothes Censer.” Originally (such devices) had been connected with Fang Feng, but afterwards the method had been lost until (Ting) Huan again began to make them. He fashioned a contrivance of rings which could revolve in all the four directions, so that the body of the burner remained constantly level, and could be placed among bedclothes and cushions. For this he gained much renown.⁹

長安巧工丁緩者，又作被褥香爐，一名被中香爐，本出房風，其法後絕。至緩始更為之，為機環轉運四周，而爐體常平，可置之被褥，故以為名。

Having read *Hsi Ching Tsa Chi*, Liu Xianzhou discovered records of Ting Huan 丁緩 constructing fans but failed to notice records of him constructing the “Bedclothes Censer.”¹⁰ With Wang Ling’s 王鈴 (1917–1994) assistance, Needham uncovered the “Bedclothes Censer” in *Hsi Ching Tsa Chi* for the first time and was assured that a Chinese account of the gimbal is “much earlier than anything in Europe or Islam except the dubious passage in Philon.”¹¹ He then suggested that “If we adopt the cautious view and regard the gimbals of Philon of Byzantium as a late Arabic interpolation, then the credit is Ting Huan’s (or Fang Feng’s), and it is not unlikely that the role of the Arabs was to transmit the device from further east.”¹²

Needham placed a high premium on issues such as how technologies emerged and circulated, going far beyond his Chinese counterparts in this respect. For example, he noticed that Ssuma Hsiang-Ju 司馬相如 (ca. 140 BCE) mentioned *Jin za xunxiang* 金錘薰香 (the metal rings [contained the] burning perfume) in *Mei Jen Fu* 美人賦 [Ode to beautiful women]. In

8. Needham, SCC, 4.2:231.

9. Needham, SCC, 4.2:233.

10. Hsien-Chou Liu, *Zhongguo jixie gongcheng famingshi* 中国机械工程发明史 [History of inventions in Chinese mechanical engineering], 1st ed. (Beijing, 1962), 38.

11. Needham, SCC, 4.2:233.

12. Needham, SCC, 4.2:236.

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accordance with this, an inference was drawn that *Jinza xunxiang* was referred to as the device with a gimbal suspension, meaning that “it is possible that the invention belongs to the -2nd rather than to the +2nd century.”¹³ Needham even suggested that the gimbal might be derived from the construction of armillary spheres “since their rings also had to be pivoted one within the other.”¹⁴ In this case, the complicated issue as to the time of armillary spheres’ origin is involved.

Judgment of the Historical Status of Inventions and Inference of Technology Dissemination

Joseph Needham was particularly concerned about the invention and dissemination of technology in Eurasia. The astronomical clockwork, as the “soul” of the mechanical clock, is a special case to which Needham paid attention.

Early in the 1930s, the astronomer Chu Wen-Hsin 朱文鑫 (1883–1939) first discovered the eleventh-century Chinese “Astronomical Tower,” which was constructed by Su Sung 蘇頌 (1020–1101) and Han Kung-Lien 韓公廉 and their co-workers, through *Hsin I Hsiang Fa Yao* 新儀像法要 [Essentials of methods of constructing the new armillary sphere and celestial globe, 1094–1096]. He held the belief that “The methods of later-generation of clockworks all fall into the spectrum involved in the astronomical tower.”¹⁵ In 1953 and 1954 Liu Hsien-Chou published a series of articles that explicated how the astronomical tower could simultaneously drive the timing device, celestial globe, and armillary sphere using one waterwheel. He pointed out that “celestial balance” can realize the isochronal and discontinuous operation of the waterwheel and the whole instrument.¹⁶

By means of comparisons with European clocks, Needham, Wang Ling, and Derek J. Price further judged the significance of the astronomical tower in the history of mechanical invention. In March 1956 their article entitled “Chinese Astronomical Clockwork” stated that “It thus appears that the Chinese tradition of astronomical clock was more nearly in the direct line of ancestry of the late medieval European mechanical clocks” and emphasized that the device, which controlled the rotation of a waterwheel, was a special escapement.¹⁷ This paper was rendered into Chinese by Xi Zezong 席泽宗 (1927–2008) and generated attention from Chinese

13. Needham, SCC, 4.2:234.

14. Needham, SCC, 4.2:236.

15. Wen-Hsin Chu 朱文鑫, *Tianwenxue xiaoshi* 天文學小史 [Short history of astronomy] (Shanghai, 1935), 48–49.

16. Hsien-Chou Liu 劉仙洲, “Zhongguo zai chuandongjijian fangmian de faming” 中國在傳動機件方面的發明 [Inventions of China in transmission mechanism], *Jixie gongcheng xuebao* 機械工程學報 [Journal of mechanical engineering], 1954, 2: 1–37.

17. Needham, Wang, and Price, “Chinese Astronomical Clockwork,” 600–602.

historians of science and technology, such as Liu Hsien-Chou and Wang Chen-To 王振鐸 (1911–1992). In early September 1956 Liu Hsien-Chou, who participated in the VIII Congresso Internazionale di storia delle scienze held in Florence, had an exchange with Needham during the congress.¹⁸ Wang Chen-To and his co-workers constructed a one-fifth scale model of the astronomical clock-tower in 1958.¹⁹ For the Science Museum in London, the British scholar John H. Cambridge constructed an operational model of the astronomical tower.²⁰

Published in 1960 and co-authored by Needham, Wang, and Price, *Heavenly Clockwork: The Great Astronomical Clocks of Medieval China* cited Liu Hsien-Chou's papers. Coming out in 1965, the subvolume on mechanical engineering of Needham's SCC devoted one-sixth of its length to the discussion of "clockwork: six hidden centuries," namely the history of clocks (the astronomical tower and related objects). Needham asserted that the "water-wheel linkwork escapement" of the eleventh-century astronomical tower marked the world's earliest escapement.²¹ He further traced its descent back to the eighth century: I-Hsing 一行 (683–727 CE), Liang Ling-Tsan 梁令瓚, and their co-workers succeeded in constructing an astronomical instrument in 723 CE that was the first of all escapement clocks.

Needham was of the opinion that "the Chinese escapement constitutes an intermediate stage between the time-measuring properties of liquid flow and those of mechanical oscillation."²² It thus unites the clepsydra and the mechanical clock in one continuous line of evolution. On one hand, he believed that "The weight-drive descended from the floats of the Hellenistic anaphoric clocks and mechanical puppet theatres."²³ On the other hand, he emphasized that the Chinese invented the escapement six centuries earlier than the Europeans, which to him suggested "that at least the diffusion stimulus travelled from east to west."²⁴ The "stimulus diffusion" he envisioned was "to imagine that the transmission was of the stimulus diffusion type only, and that firm conviction of the prior successful solution of the problem elsewhere led European scholar-artisans to solve it themselves in a different manner."²⁵ Needham tried to "see whether any

18. Needham, Wang, and Price, *Heavenly Clockwork: The Great Astronomical Clocks of Medieval China: Chinese Astronomical Clockwork* (Cambridge, 1960), 57.

19. Chen-To Wang 王振鐸, "Jiekai le woguo 'tianwenzhong' de mimi—Songdai shuiyun yixiangtai fuyuan gongzuo jieshao" 揭開了我國"天文鐘"的秘密——宋代水運儀象台復原工作介紹 [Unveiling the secret of Chinese astronomical clockwork: Introduction to the restoration of the Song astronomical tower], *Wenwu cankao ziliao* 文物參考資料 [Cultural relics reference materials], 1958, 9:1–9.

20. Needham, "Astronomy in Ancient and Medieval China," *Philosophical Transactions of the Royal Society of London A* 276 (1974): 67–82.

21. Needham, SCC, 4.2:435–62.

22. Needham, SCC, 4.2:462.

23. Needham, SCC, 4.2:532.

24. Needham, SCC, 4.2:534.

25. Needham, SCC, 4.2:544.

help can be found from the Islamic and Indian culture-area” and drew a road map to show roles of different culture-areas in the evolution of mechanical clockwork.²⁶ However, Needham never found the clue he was looking for.

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Difficulties in the Argumentation of Knowledge Dissemination and the Risk of Error

Given the scarcity and incompleteness of the remaining ancient historical materials, it is no easy task for any historian to provide complete and satisfying arguments about the origin and avenues of dissemination of technologies. Attempting to do so therefore incurs some risk. One opinion has it that Needham’s view of the global history of science, which emphasizes cross-cultural dissemination, is flawed. The “anticipations” and disseminations he posited are in various cases problematic.²⁷ An example lies in the fact that despite Needham’s belief of *Jinza xunxiang* in *Mei Jen Fu* being a gimbal suspension, *Mei Jen Fu* had no specific depictions of this device. For another example, Needham boldly speculated: “It is not yet excluded that the water-wheel linkwork escapement goes back to Chang Heng 張衡 himself.”²⁸ In fact, historical materials only mentioned that Chang Heng made the water-driven celestial globe in the second century but did not refer to any mechanism controlling its steady rotation.

Regarding the inference of Needham, Wang, and Price that Su Sung’s astronomical clock could have influenced the West by stimulus diffusion, scholars such as David S. Landes considered it unreasonable.²⁹ In fact, Chinese mechanical clocks and European ones belong to two independent technological traditions. For European clocks, the escapement is indispensable, allowing the weight or spring to drive the gear system slowly. For the Chinese mechanisms, the steady flow of water from clepsydra is channeled into scoops to produce the torque that drives the water-wheel. The escapement exerts direct control over the waterwheel, which is made to periodically rotate. Evidently, “the major part of the time-keeping was effected by the constancy of the flow of the water.”³⁰ In the twelfth century the astronomical tower was dismantled, and later generations’ attempts at restoration failed. It seems unlikely that the astronomical tower influenced the Europeans who invented mechanical clocks.

To take another example, Needham believed European efforts to convert the direction of motion in machinery happened during “the funda-

26. Needham, SCC, 4.2:533.

27. Blue, “Science(s), Civilization(s), Historie(s).”

28. Needham, SCC, 4.2:532.

29. David S. Landes, *Revolution in Time: Clocks and the Making of the Modern World* (Cambridge, Mass., 1983), 18–27.

30. Needham, SCC, 4.2:545.

mental revolution” in seventeenth- and eighteenth-century Europe but claims that the Chinese did so much earlier. He pointed out that Chinese first made the piston-bellow and the combination of eccentric, connecting-rod and piston-rod during or even prior to the Song Dynasty (ca. 1000 CE), thereby inventing the interconversion of rotary and rectilinear motion. In light of the time difference, he suggested it was probable that a direct genetic connection existed between the European “ex-piston” and the Chinese “ad-piston.”³¹ In other words, Chinese machinery, such as the blowing-engine and silk-reeling machine, may have helped pave the way for the interconversion of rotary and rectilinear motion, which was so central to the European invention of the steam engine. However, his claim is uncorroborated by the evidence, leading to the suspicion that Needham’s claims probably exaggerated the influence of Chinese inventions on the West.

Indeed, comparative research on knowledge in different regions and traditions may be one of the most complicated and difficult issues a historian can undertake, and the results usually provoke hot debates, as was the case with Needham’s research. Nevertheless, it is still one of the most effective methods for developing a global understanding of the history of technology and science. In the CAS Institute for the History of Natural Sciences, a group of scholars concentrates specifically on comparative research of science and technology, starting with the study of selective cases. This group seeks a deep understanding of the multilinear development and dissemination of knowledge. Such research requires detailed analyses of relevant sources, accurate models of the development and dissemination of knowledge, as well as knowledge of different cultural and social contexts of science and technology. A global picture of the history of science and technology needs international collaboration and interdisciplinary research.

Conclusion

Needham’s *Science and Civilisation in China* significantly advanced the comprehension of Chinese cultural traditions and offered a fresh take on the history of science and technology through the approach of “connected histories.” With a broad academic vision, he combined macronarrating with microverifying and performed comparisons between Chinese science and technology and equivalent knowledge in other civilizations. Not only did he develop in-depth understandings of Chinese traditions of science and technology, his work also yielded multiple credible and illuminating conclusions.

As the “chief designer” of SCC, Needham utilized categories of modern science as a reference to identify China’s scientific discoveries, technological inventions, and innovations. Considering the consistency or similarity of knowledge, he inferred or concluded the cross-cultural knowledge rele-

31. Needham, SCC, 4.2:387.

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vance and knowledge dissemination, and proposed the origins of knowledge and possible paths or means. It was his predilection to illustrate the spread of certain technologies with the concept of “stimulus diffusion.”

Needham’s collaborators were integral to the composition of the SCC. The subvolume on mechanical engineering was accomplished with the aid of Wang Ling. Wang did not substitute for his authorship but sought sources and literature for him, especially within Chinese historical texts.³² The principal professional backgrounds of Needham and Wang were biochemistry and history, respectively, but they nevertheless worked to provide an accurate and profound grasp of mechanical engineering in their volume on this subject. Indeed, SCC shows their valuable appreciation for technical details.³³ As a result, they demonstrated that Chinese people had a deep understanding of machines, and they put these developments into worldwide context of the development of mechanical engineering. A fly in the ointment is the obvious shortage of knowledge about manufacturing technology in the context of the whole discipline of mechanical engineering.

Admittedly, some of Needham’s arguments reveal that his assumptions might have been a little too bold, with insufficient evidence provided to verify them. Nevertheless, the virtues cannot be obscured by the defects. As great a scholar as he was, Needham left SCC as a tremendous academic legacy, which remains an important resource for international scholars to comprehensively understand the traditions of Chinese science and technology. His questions and attempted answers are enlightening, and his methodologies for cross-cultural comparative research merit emulation.

32. Peng Yoke Ho 何丙郁, “Liyuese yu ‘Liyuese zhimi’: Jijiang mianshi de Zhongguo kexue jishushi ‘jieshupian’” 李约瑟与“李约瑟之谜”: 即将面世的《中国科学技术史》“结束篇” [Joseph Needham and the “Needham question”: The upcoming “final chapter” of SSC], in *Zhongguo kexue yu kexue geming: Liyuese nanti jiqi xiangguan wenti yanjiu lunzhu xuan* 中国科学与科学革命: 李约瑟难题及其相关问题研究论著选 [Science in China and scientific revolution: Selected works on the Needham question and its pertinence], ed. Liu Dun 刘钝 and Wang Yangzong 王扬宗 (Shen-yang, 2002), 124–36.

33. Blue, “Science(s), Civilization(s), Historie(s).”