

TOWARDS A FRUITFUL FORMULATION OF NEEDHAM'S GRAND QUESTION

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ABSTRACT

As it stands, Needham's Grand Question is simply too general and ill-posed to be answered in a meaningful way. In this paper it is argued that Needham's Grand Question, to wit *Why did science emerge in the West and not in China?*, can only be fruitfully pursued, (1) on the condition that one explicates the assumptions and conceptions involved in an informative and motivated way, and (2) on the condition that the question is concretized and fine-tuned by means of and in terms of a series of specific questions. In this paper, I attempt to reformulate Needham's Grand Question on the basis of a minimal conception of modern science. Next I will split up the Grand Question into a series of more specific, controllable and arguably more fruitful questions.

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1 Aim

Why do people keep asking why the Scientific Revolution did not take place in China when they know enough not to explain why their names did not appear on page 3 of today's newspaper? (Sivin 1985, p. 42)

Needham put the following question on the plate of historians of science: why did modern science emerge in the West and not in China? Needham himself sometimes associated this issue with the question as to why there was no Industrial Revolution in China – however, to avoid confusion and unnecessary complexity, I shall keep the two questions asunder and consider the former question only. Here I do not attempt to assess Needham's China studies in any way. It goes without saying, that the material which Needham provided in the substantial *Science and Civilisation in China* series offers a cornucopia of material that is relevant for understanding Chinese science.

Following Sivin 1985, many have come to criticize the Needham question. While agreeing with some of the criticisms that have been raised, I do not think that it implies that variants of the question are intrinsically meaningless as well, or so I will argue. One *caveat* from the outset: throughout the paper, I remain thoroughly agnostic about any socio-economical, institutional, philosophical, cultural or pedagogical factors that one may come up with in order to provide an answer to Needham's *explanandum*.¹ I shall be exclusively occupied with arriving at a fruitful formulation of Needham's Grand Question (cf. Cohen 2001). In section 2, we will take a look at the status which Needham ascribes to modern science. It turns out that Needham remains somewhat vague when it comes to characterising modern science and, obviously, such

¹ On such factors, see the papers by David De Saeger and Bart Dessein in this volume and the references therein.

conceptual vagueness needs to be addressed. In order to remedy this undesirable situation, I shall, in section 3, provide a minimal conception of modern science and reformulate the Needham question in view of it. Accordingly, in this section I shall provide a more detailed characterization of 'modern science'. Finally, in section 4, I shall provide a list of questions which naturally follow from my reformulation of Needham's Grand Question.

2 The status of 'modern science' according to Needham

As it stands, Needham's question simply assumes that "modern science" is an easily identifiable entity. However, what do we mean exactly when we assert that "modern science" was absent in China? Are we referring to *descriptive* sciences such as botany, geography, natural history and the like, or rather to *theoretical* sciences such as dynamics and mechanics? Or do we mean *pure* as opposed to *applied* science? Or, do we refer, more specifically, to *mathematical* sciences? Or to *empirical* or *experimental* sciences?

From the material that is surveyed in *Science and Civilisation in China* (henceforth: *SCC*),² it becomes clear that Needham was not referring to the absence of descriptive sciences in China. This is clear from his detailed treatment of the Chinese botanical tradition (see *SCC*, VI, Part I). Given the ample attention Needham dedicated to applied science and technology³ it is obvious that Needham was not referring to the absence of applied science either (see especially *SCC*, IV, Part 2 [on mechanical

² For a succinct synthesis of Needham's China studies, see Cohen 1994, pp. 418-482.

³ To Needham applied science and technology were synonymous (Needham 1973, p. 3).

engineering]; *SCC*, IV, Part 3 [on civil engineering and nautics]; and *SCC*, V, Parts 6-13 [on military, textile, metallurgic, and ceramic technology and mining]). Moreover, Needham frequently stressed the centrality of applied science in Chinese culture. Since in the third volume of *SCC* Needham scrutinized Chinese mathematics, which was more algebraic than geometrical, rejecting the absence of mathematical sciences was not an available option for him. In Chinese science, there also was attention for quantitative measurement as the book *Huai Nan Tzu* (before 120 B.C.) testifies (*SCC*, IV Part 1, pp. 15-17). In the *Mo Ching* (ca. 300 B.C.), the Mohist canon, several propositions are collected, which testify of an abstract-theoretical approach to the natural world. Examples of such propositions are the following:

- When an object is moving in space, we cannot say (in an absolute sense) whether it is coming nearer or going further away.
 - (The idea of space is like the idea of) duration. (You can select a certain point in time or space as the beginning, and reckon from it within a certain period or region, so that in this sense) it has boundaries, (but time and space are alike) without boundaries.
 - Motion is due to a kind of looseness (i.e. to the absence of an opposing force).
 - The cessation of motion, is due to the (opposing force) of a ‘supporting pillar’.
 - If there is no (opposing force) of a ‘supporting pillar’ the motion will never stop.
- (*SCC*, IV, Part 1, pp. 55-56)⁴

“What remains in these brief fragments,” Needham wrote, “is so striking that we may be allowed to believe that if more of the physics of the Mo-

⁴ I have omitted Needham’s insertion of the original Chinese terms.

hist school⁵ had been preserved, we should have found in it, some discussion of trajectories, the effect of gravity, and so on." Moreover, "if the Mohists had no technical term corresponding to impetus, at least they did not suffer from the concept of 'natural place' or the awkward idea of antiperistasis" (*SCC*, IV, Part 1, p. 58). The Mohists also possessed theoretical understanding of Archimedes' law of the lever. Denying the presence of a theoretically-oriented scientific approach in Chinese culture was therefore not an option for Needham.

When working oneself through Needham's tomes, it becomes clear that, when Needham discusses "modern science," he is referring to *a particular integration of mathematics, experimental testing, and theory* (and the open publication of the results harvested thereby):

The birth of the experimental-mathematical method, which appeared in almost perfect form in Galileo, and which led to all the developments of modern science and technology, presents the history of science with one of its most important and complex questions. Though we cannot do it justice, a brief analysis here will not be out of place, for only in this way can we gain some idea how it was exactly that mathematics and science came together at the Renaissance, and how far they had remained apart in earlier medieval, as in Chinese, society. (*SCC*, III, p. 156, cf. *SCC*, VII.2, p. 24).

Unfortunately, he did not add much as to the specifics of the particular integration involved. Occasionally he seems to have associated it closely with the hypothetico-deductive method (*SCC*, III, p. 156). As is clear from the above quotation, Needham ascribed a pivotal role to the age of Galileo and his contemporaries:

⁵ See *SCC*, II, pp. 165-203.

When we say that modern science developed only in the Western Europe in the time of Galileo during the Renaissance and during the scientific revolution, we mean, I think, that it was there alone that there developed the fundamental basis of *modern* science, such as the application of mathematical hypotheses to Nature, and the full understanding and the use of the experimental method, the distinction between primary and secondary qualities, and the systematic accumulation of openly published scientific data. Indeed, it has been said that it was in the time of Galileo that the most effective method of discovery about Nature was itself, and I think that is still quite true. Nevertheless, before the river of Chinese science flowed, like all other such rivers, into the sea of modern science, China had seen remarkable achievements in many directions. (Needham 1981, p. 9)

Needham's characterization of modern science was far from crystal clear and exact. Although he suggested that "the application of mathematical hypotheses to Nature" was somehow involved and that modern science encompassed "the full understanding and the use of the experimental method," he did not further elaborate on these issues. By contrast in China, "[t]here is no one to correspond to the so-called 'precursors of Galileo', men such as Philoponus and Buridan, Bradwardine and Nicolas d'Oresme," Needham pointed out, "and hence no dynamics or cinematics [sic]" (*SCC*, IV, Part 1, p. 1). Three branches of Chinese science, however, were particularly developed in ancient and medieval China: optics, acoustics and magnetism – the study of which emerged and was cultivated in the Mohist tradition. On the other hand, mechanics was "weakly studied and formulated" and dynamics was "almost absent" (*SCC*, IV, Part 1, xxiii).

Note also that Needham oftentimes closely aligned the rise of modern science with atomism, discontinuity, and linear thinking, which was in opposition with the Chinese wave-like conception of nature (*SCC*, IV,

Part 1, pp. 3-14).⁶ He also ascribed an organic, rather than mechanical, view of nature to the Chinese.⁷ Recent work in the history of Western science has shown, however, that the ascription of a purely mechanical character to seventeenth-century and eighteenth-century science is far from unproblematic (e.g. Henry 1989 and Dobbs 1991). It deserves being pointed out that my reservation on this point is mainly motivated by the fact that there is a lurking danger inherent in Needham's casual ascriptions, namely a potential disproportional attention to specific *scientific doctrines, conceptions or beliefs*, rather than a focused attention to a specific *method relied on to make knowledge claims about the empirical world* (cf. the discussion of *actio in distans* in *SCC*, IV Part 1, p. 60). In order to transform the Needham question (henceforth: NQ) into more manageable questions, we require a *fruitful conception of modern science* and, more specifically, *an adequate characterization of the particular integration of mathematics, experimental testing, and theory involved*, which I shall both provide in the following section.

3 A minimal conception of 'modern science'

'Modern science' refers to a scientific approach which was primarily shaped in the seventeenth century. In this section, I attempt to provide a characterization of the specific sort of science referred to and rephrase the NQ accordingly. To begin with, the NQ calls for an explanation of why a *specific sort of scientific thinking and practice became dominant* in one culture and not in another. The aim of NQ is not so much to explain the

⁶ Needham noted that the Chinese never applied such wave-conceptions specifically and systematically to the interpretation of physical phenomena (*SCC*, IV, Part 1, p. 12).

⁷ In the first volume of *SCC*, Needham asked: "how was it the Chinese *backwardness* in scientific theory co-existed with the growth of an organic philosophy of Nature?" (*SCC*, I, p. 4 [italics added]).

absence of modern science in China, but rather to help to track certain factors that played a role of significance in the emergence of modern science in the West (cf. Cohen 2007, p. 499).

Allow me to provide some preliminary clarifications:

- Note that I have deliberately decided not to formulate NQ in terms of the (non-) occurrence of the Scientific Revolution (*pace* Sivin 1985 and Singh 1987), because the latter frequently raises concern. One might dispute on whether ‘the Scientific Revolution’ is an adequate term to denote this particular process in the history of Western science. However, no present-day historian of science conceives of its *signifié* as a radically discontinuous process that happened overnight. Moreover, it is undeniably so that by the seventeenth century our ideas about how to obtain knowledge of the empirical world had changed significantly. That one cannot provide a strict *terminus a quo* and *ad quem* for this process is a natural consequence of its accumulative nature, rather than a real worry.
- Secondly, the words “a specific sort of scientific thinking and practice” are meant to avoid all undertones of cultural superiority or teleology, which has unfortunately accompanied the NQ (see the examples in Dun 2000).⁸ However, the problem dissolves when

⁸ E.g. Sivin’s laments: “These assumptions are usually linked to a belief – or a faith, if you prefer – that European civilization all along was somehow in touch with reality in a way no other civilization could be, and that its great share of the world’s wealth and power comes from some intrinsic fitness to inherit the earth that was there all along.” (Sivin 1985, p. 43), “For the past of other civilizations the test is always anticipation of or approximation to some aspect of early European science, or modern science.” (ibid., pp. 45-46), and “In other words, if one begins with the assumption that the paramount issue in the study of China is accounting for the inevitability of backwardness, one is unlikely to question

one conceives of the NQ as a question in *comparative* history of science: what we are doing is determining the differences between Western and Chinese science and providing an explanation of these differences.

As we have seen previously, the sort of scientific thinking and practice referred to consists of *a particular integration* of mathematics, experimental testing, and theory. In what follows, I will clarify what the latter consists of and, in doing so, I will provide *a minimal conception of modern science*. First of all, I consider the following features as relevant characteristics of modern science:

- *Scientia operativa*. A major characteristic of modern science was that it broke with the Aristotelian separation between *naturalia* and *artificialia* in a systematic way. Aristotle had argued that in the formation of products of nature and in the formation of manmade products different principles were at play. More specifically, he emphasized that human interventions in nature disturb the normal course of things and thus offered no legitimate way of obtaining knowledge about the natural world. By the seventeenth century, natural philosophers had become convinced that there is no ontological difference between the spontaneous workings of nature and the workings which are directed or manipulated by man's purposive action (see Ducheyne 2005 and 2006 for specific case-studies). Bacon's project of reform was to be founded on "natural

whether backwardness was inevitable, to ask whether there were not in her history prominent patterns of success from which we might learn, or to re-examine the assumptions about the modernized West that organize European history as a crescendo of success (with setbacks, to be sure, adding to the complexity and thus the charm of the crescendo)." (ibid., p. 46).

and experimental history”, i.e. on a detailed survey of specific phenomena as they occur in the spontaneous course of nature, on the one hand, and on a systematic experimental study of nature “under constraint and vexed (*natura constricta et vexata*),” i.e. nature “when forced out of her natural state by art and the hand of man, and squeezed and moulded (*cum per artem et ministerium humanum de statu suo detruditur, atque premitur et fingitur*),” on the other (Bacon 1887-1901, VIII, p. 48 (= *ibid.*, I, *Instauratio magna, Distributio operis*, p. 222).⁹ While there is currently no widespread consensus as to which traditions and thinkers were actually responsible for the rise of a *scientia operativa* (e.g. Pérez-Ramos 1988 and Smith 2004), the claim that the idea of a *scientia operativa* was central in seventeenth-century thinking is widely accepted.

• **Interventionism.** During the seventeenth-century a new scientifically useful notion of causality emerged, which was connected to the idea of a *scientia operativa*. This new notion of causality is an interventionist notion. According to such notion, causal relations can be discovered by actively exploring and manipulating natural processes. In order to know nature, we basically have to intervene in nature. Generally: if we wish to explore whether *A* is a cause of *B*, we will need to establish whether deliberate and purposive variations in *A* result in changes in *B*, thereby keeping other variables as fixed as possible. Paradigmatic of this is the following text by Galileo:

⁹ According to Bacon, nature exists in three states: nature in its free and ordinary course (*species*), nature forced out of her natural state by violent impediments (*monstra*), and nature constrained and moulded by art and human ministry (*artificialia*) (Bacon 1887-1901, II, *Instauratio magna, Parasceve*, i, p. 47).

Therefore, commencing to investigate with examination by exact experiment how true it is that shape does not at all affect the sinking or not sinking of the same solids, and having already demonstrated how a greater heaviness of the solid with respect to the heaviness of the medium is the cause of its ascending or descending, [then] *whenever we want to make a test of what effect diversity of shape has on the latter, it will be necessary to make the experiment with materials in which variety of heaviness does not exist.* For were we to make use of materials that could vary in specific weight from one to another, when we encountered variation in the fact of descent or ascent we would always remain with ambiguous reasoning as to whether the difference derived truly from shape alone, or also from different heaviness. (Drake 1981, p. 74 [italics added])

Connected to interventionism is the notion of a (relatively) closed physical system. A (relatively) closed physical system is a (relatively) isolated system which is maximally independent from its environment: ideally, there are no interactions between components of the system and the surrounding environment. A closed physical system is intended to screen off external influences – and hence, if successful, it warrants that no external influences, other than those we produce ourselves, need to be adduced for the effects we observe in the system under consideration (see Ducheyne 2005 and 2006).

- ***Experiment and mathematics.*** Contrary to an experience, an experiment presupposes the involvement of a specific question about nature which the experimental outcome is designed to answer (Dear 1995, pp. 21-23). Experiments always describe specific events and attempt to provide answers to specific questions. Robert Hooke, for instance, recorded that experimental “queries” are to be accompanied by a specification of those observations or experimental outcomes that would answer the question at stake, i.e. a

natural philosopher is to specify “what Observations, Examinations, or Experiments would seem conducive thereunto, and accordingly under every such Query of Question, he ought to set down the things requisite to be known for the obtaining the full Knowledge of a compleat and full Answer to it” (Hooke 1705, p. 33). In an experiment a physical process is deliberately manipulated in a controlled and quantified manner. Furthermore, by quantifying physical parameters, mathematical patterns in the data could be sought for. Experimentation obviously squares nicely with interventionism. Replicating and reproducing experimental designs were crucial in the establishment of modern science. Procedures of epistemological control, such as having experiments witnessed and attested by qualified observers were crucial to the establishment of experimental results. This presupposed an explicit social technology, i.e. a set of rules scientists should use in dealing with each other and considering knowledge claims, and a literary technology, i.e. a written account composed in such a way so that those who did not witness the experiment are familiarized with the experimental accounts and that one could find the required information to re-do the experiment, if one chooses to do so (Shapin & Schaffer 1985).

- **Physical laws.** Scientific laws and theoretical principles (e.g. the laws of motion) were obviously quintessential in the establishment of modern science. Such theoretical principles served as abstract inferential tools from which conclusions could be derived once specific information is provided.

However, by providing a series of characteristic features of modern science, we have not yet arrived at a *minimal conception* of modern science. What we need in addition to them is a characterization of how these features were *integrated*:

(MC) When doing modern science, Western natural philosophers accepted the following precept: *in order to obtain knowledge about the empirical world, one should rely on systematically quantified observations or on the results produced by actively intervening in natural processes in a controlled manner by means of experimental designs (whereby the results of the experimental set-up at hand are quantified) and explain the observed phenomena by reference to a set of physical laws or theoretical principles.*

Let me illustrate this with an example. In Book I of the *Principia*, Newton established a systematic dependency between the presence of certain forces and specific (observable) mathematical properties that characterize the motion of the bodies being acted upon by these forces, *in casu* he related inverse-square centripetal forces to Keplerian motion.¹⁰ When demonstrating this, he relied on conclusions entailed by the laws of motion. By Law I he was able to infer the activity of an impressed or centripetal force from non-inertial motion, by Law II he was able to infer the magnitude and direction of an impressed or centripetal force producing non-inertial motion, and by Law III he was able to relate the impressed or centripetal force to its corresponding reaction force. In this way, he was able to integrate (astronomical) observation, mathematics and the laws of motion. Taking MC into consideration, NQ becomes:

(NQ₁) Why did the precept that *in order to obtain knowledge about the empirical world, one should rely on systematically quantified observations or on the results produced by actively intervening in natural processes in a controlled manner by means of experimental*

¹⁰ Since I only want to make a general point here, I have simplified this discussion of Newton to the extreme. Details are spelled out in Ducheyne 2009 for instance.

designs (whereby the results of the experimental set-up at hand are quantified) and explain the observed phenomena by reference to a set of physical laws or theoretical principles become dominant in the West and not in China?

In China mathematics was highly evolved, an abstract-theoretical approach to the study of nature was at hand in the writings of the Mohists, and empirical sciences were practised. However, from the *Science and Civilisation in China* series it appears that an experimental approach – in the sense outlined above – was not highly developed.¹¹ Taken this into account, **NQ₁** becomes:

(NQ₂) Why did the precept that in order to obtain knowledge about the empirical world, one should rely on systematically quantified observations or on the results produced by actively intervening in natural processes in a controlled manner by means of experimental designs (whereby the results of the experimental set-up at hand are quantified) and explain the observed phenomena by reference to a set of physical laws or theoretical principles become dominant in the West and not in China, *despite a highly developed mathematical corpus, an abstract-theoretical approach to the study of nature, and the practise of empirical sciences?*

Hereby we have arrived at a more exact formulation of NQ. That **NQ₂** is fruitful can be seen from the questions which naturally follow from it.

¹¹ I consider this issue as an integral part of the NQ and strongly encourage further research of this matter.

4 From the Grand Question to manageable questions

Given the present state-of-the-art, it seems to be too soon to provide an answer to **NQ**₂. Before we can provide a(n) (partial) answer to it, we will need to find answers to some smaller, but more manageable questions. It is important to note that these questions are not sub-questions to Needham's Grand Questions, but rather particular questions which need to be answered before one can reasonably address the Grand Question. As I have argued previously, modern science refers to a *particular integration* between *mathematics*, *experimental testing* and *theory*. In what follows, I will list some examples.

4.1 Questions on mathematics

Did the Chinese insist on quantifying empirical phenomena? And if so, to what extent?

Did quantitative accuracy play a role in the evaluation of knowledge claims on the empirical world? And if so, in what way?

Was prediction predicated under quantitative accuracy? And if so, to what extent?

Were quantified relations between empirical phenomena seen as providing a mere descriptive account of the phenomena at hand or as a crucial element in providing explanations of them?

4.2 Questions on *scientia operativa*, on interventionism and experiment

How did the Chinese conceive of *naturalia* and *artificilia*?

Did or did they not make an ontological separation between both?

Did they think that by actively intervening natural phenomena were disturbed from their natural course (*contra naturam* versus *secundum naturam*)?

Did the Chinese perform experiments in relatively closed systems?

Did they apply screening-off procedures in order to keep specific variables constant?

Did they systematically quantify empirical data?

Did they conceive it as their business to raise specific questions about nature which the outcome of a physical process is designed to answer?

Did the Chinese have a tradition of witnessed or public experimentation?

Were scientific accounts written so that the reader could gather sufficient information to re-enact the procedure described?

4.3 Questions on theoretical principles and laws

Did the Chinese use theoretical principles or laws which served as abstract inferential tools from which conclusions could be derived once specific information is provided?

Did theoretical principles or laws allow the Chinese to provide a theoretical interpretation of natural phenomena?

What are the similarities and differences between the conception of physical principles developed by the Mohists and those developed in the West?

4.4 Questions on the integration between mathematics, experimental testing and theory

Did the Chinese relate observable mathematical regularities to a theoretical account of these regularities?

When explaining natural phenomena, did they proceed from theory to quantified data or conversely? And if so, in what way(s)?

What is the role of theory and theoretical principles in Chinese science?

By paying scholarly attention to these specific questions, we might perhaps, in a few decades, come closer to providing a rich and subtle answer to Needham's Grand Question.

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