Picturing Technology in China

From Earliest Times to the Nineteenth Century

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Preface

The disparagement that once pervaded much of Western thinking and writing about China's record in science and technology has now long given way to a general recognition that achievements in these realms constitute one of the great triumphs of the Chinese people and their civilization. In the area of technology, more than two generations of scholarly effort, much of it inspired by Joseph Needham and the volumes of his *Science and Civilisation in China*, have fleshed out a remarkable story of Chinese inventive genius and a broad Chinese talent for technological innovation that could hardly have been guessed at before the middle of the last century.

Parts of that story, however, remain to be fleshed out. For our purposes, none is more important than the question of how Chinese approaches to portraying technology influenced the overall development of technology in China. Until relatively recently, much of the work on surviving images of premodern technology analyzed these images, often with considerable skill, to elucidate how a particular technology or piece of equipment worked. From these studies have emerged many interesting insights into how the visual depiction of technology, as well as the technology itself, did or did not change over time.

One of our purposes in this volume will be to pull together many of these insights into an overview of what we presently understand about the illustrations of technology in China up to about the nineteenth century. At the same time, we shall pay special attention to newer approaches that are now beginning to deepen our understanding of the place of both technology and portrayals of technology in the larger Chinese sociopolitical, economic, and cultural order.

It will rapidly become clear that much of what I have to say has been inspired by that vast body of work on the portrayal of technology in European culture, especially in the late Middle Ages and the Renaissance. But despite the fact that the images produced by the artists of the Renaissance generally conform much better than most Chinese images to what we, with our twenty-first-century perspective, tend to expect from technological illustrations. Despite this, I shun the all-too-common approach that sets up the European achievements as some kind of universal standard and then seeks explanations for why the Chinese were unable to meet that standard. I am above all interested in understanding the complex of motivations that led the Chinese to produce the images they did, not why they "failed" to produce images more like those in Europe. When I reference the European experience, it is mainly to help us identify what was particularly distinctive in the Chinese experience, and perhaps suggest roots of that distinctiveness.

Moreover, it deserves to be noted that, seen in a broad historical perspective, the Chinese illustrations by no means infallibly failed to measure up to contemporary European illustrations even when judged by criteria that were much less emphasized by Chinese than by Westerners. As early as the Song dynasty (960–1278), Chinese artists on occasion produced illustrations of technological subjects that displayed a degree of accuracy, intelligibility and even realism generally not found in European images until much later. To take just one example, we can contrast the copy of a thirteenth-century Chinese illustration of the reeling or unwinding of silk fibers from cocoons in Fig. 0.1 with the spinning and weaving scene from a fourteenth-century Flemish manuscript in Fig. 0.2.

To be sure, most Chinese illustrations of technology in this period fell far short of the realism and precision of the remarkable series of painted illustrations of farming and sericulture of which Fig. 0.1 is only one example. But one will search in vain for any European portrayals of technology from these centuries that could match them.[1] After about the thirteenth century, however, one seems to see rather less advance in Chinese portrayals of technological subjects than earlier achievements might have portended. Here, too, attempting to explain why this was the case will require us to carry further our examination of the endlessly fascinating question of the interrelations between technology and broader Chinese culture.

1. For two other similarly limited European illustrations of spinning (from the early and mid-fourteenth century), see Dieter Kuhn, "Chemistry and Chemical Technology: Textile Technology," in *Science and Civilisation in China*, ed. Joseph Needham, vol. 5, part 9 (Cambridge: Cambridge University Press, 1985), 167, Fig. 107 and 168, Fig. 108.

Introduction

A useful starting point for examining how technology was portrayed in traditional China is the recognition of the place of technology in the Chinese mental landscape — or, rather, the absence of such a place. For although virtually all of the technologies that we might imagine in a traditional society were to be found in China, there was no word for and therefore no concept of "technology" in premodern Chinese. Those images that we would tend to see as portraying "technology" are part of a much larger category of images, usually referred to by the Chinese as *tu* 圖.[1] Much of the extremely varied subject matter of *tu* was of a kind that we could comfortably accept as technological, but *tu* were also used to portray an abundance of "non-technological" subject matter such as mathematics, cosmology, geography, music, ethics and magic. All of these images — and they included not only representational images but also diagrams, figures, schemata and the like — were considered to be *tu* or what Francesca Bray has called "templates for action." That is, they were seen as capable of conveying a broad range of specialist knowledge and skills that were "technological" only in the sense that they were meant to be of some kind of "practical" use. The broadness of this category *tu*, together with the absence of any overall concept of "technology," helps to explain why, although the Chinese produced a great many illustrations of technology, they never developed on any basis the concept of a special category of "technical drawings."[2]

Another reason why Chinese never came to think in terms of "technical drawings" derives from the motivations of those who produced technological images. Michael S. Mahoney, writing of Renaissance "practitioners" in Europe who did drawings of machines, provides an interesting and useful checklist of the motives that drove them: "to advertise their craft, to impress their patrons, to communicate with one another, to gain social and

1. For an excellent discussion of *tu*, to which these remarks are greatly indebted, see Francesca Bray, "Introduction," in Francesca Bray, Vera Dorofeeva-Lichtmann and George Métailié (eds.), *Graphics and Text in the Production of Technical Knowledge in China; The Warp and the Weft* (Leiden and Boston: Brill, 2007), 1–6. See also in the same volume her "Chinese Literati and the Transmission of Technological Knowledge," especially p. 299.
2. Even in Europe, as Wolfgang Lefèvre points out, technical drawings in the sense of "drawings traced by technicians for professional purposes or those derived from them" first made their appearance at the end of the Middle Ages and came to flourish only during the Renaissance; Wolfgang Lefèvre (ed.), *Picturing Machines* (Cambridge, MA: MIT Press, 2004), 2.

intellectual standing for their practice, to analyze existing machines and design new ones, and perhaps to explore the underlying principles by which machines worked, both in particular and in general."[3] It is remarkable how poorly this listing serves to suggest the motives of those who illustrated technology in China. Mahoney does not elaborate on exactly what he means by "practitioners," but we shall have occasion more than once to note the dearth of surviving Chinese illustrations produced by "practitioners" of technology, however one may choose to define the term.[4] Rather, images of technology were typically the product of painters or designers or book illustrators who had been trained as such and who did various kinds of pictures and paintings, including sometimes what we would regard as technological subjects. For them, depicting technological subjects was not intrinsically different from portraying people, trees, mountains or the other subjects on which they spent most of their time. The quality of their portrayals was seen to depend on general artistic ability as much or more than any specifically technological knowledge or expertise.

This, then, is a key point in our story: a very large proportion of the portrayals of technology in China were *not* intended, or not mainly intended, to convey technological information. Rather, they were meant to serve other goals, often especially appropriate for the artists who produced them. Aesthetically they might be aimed at arousing the interest and pleasure of viewers, or even generating an emotional response. The fifteenth-century official and writer Xia Shizheng 夏時正 expresses it well in his preface to the *Illustrated Songs on the Salines of Liangzhe*, ". . . these illustrations, which provide a general account of the salines, when taken into one's hands, will both catch the eye and excite the mind."[5] They could also be intended as visual portrayals of ideological, symbolic or moral themes. Paintings of farming practices, for example, could be intended in the first instance to symbolize a well-ordered society under the benevolent rule of the emperor, or to encourage officials to carry out their responsibilities for the welfare of the hardworking people under their jurisdiction, or perhaps to serve as a warning that all was not well in the countryside.[6] For the most part, the viewers of these images would have little or no particular interest in the technology portrayed. Hence what we are tempted to regard as technological illustrations often disappoint us when we approach them for narrowly technological information such as how an implement or machine was constructed or actually worked.[7]

3. Michael S. Mahoney, "Drawing Mechanics," in Lefèvre, *Picturing Machines*, 281. This list could be extended, for example, to include various goals associated with agreements on technological projects (convey a proposal, document an agreement, fix decisions, impose and secure control); Lefèvre, *Picturing Machines*, 4–5.

4. This is in sharp contrast with the situation in ancient and medieval Europe (as well as in Islamic lands) where there existed communities of experts who could and did write for each other while making few or no concessions for the non-expert. Bert S. Hall, "Production et diffusion de certains traités de techniques au moyen âge," in G. H. Allard and S. Lusignan (eds.), *Cahiers d'études médiévals 7; Les arts mechaniques au moyen age* (Montreal: Bellarmin, 1982), 148 ff.

5. Yoshida Tora, *Salt Production Techniques in Ancient China; the "Aobo Tu,"* trans. and rev. Hans Ulrich Vogel (Leiden: E. J. Brill, 1993), 89.

6. For many examples and detailed discussion of this point, see Hammers, *Pictures of Tilling and Weaving*.

7. Peter Jeffrey Booker, *A History of Engineering Drawing* (London: Chatto & Windus, 1963), 213. Most Chinese

For those relatively few cases where elucidation of the technology *was* the prime motive, Chinese authors instinctively relied more on text than on illustrations to convey hard technological information. In exploring why this was the case, we shall often find it necessary to consider a range of aesthetic, economic, social, intellectual and other influences that will take us well beyond any narrow focus on technology itself. Here we might simply note that most of Mahoney's motivations find no counterpart in China: there was no group of "practitioners" using technological writings to communicate with one another; almost by definition, then, no works were written "to gain social and intellectual standing" for the practice of technology; illustrations of technological subjects seem rarely if ever to have been tools for analyzing the functioning of existing machines, still less for inventing new ones;[8] and Chinese in traditional times never felt a need to try to understand the theoretical principles that underlay the functioning of machines.

It is therefore hardly surprising that the Chinese never isolated special qualities that should attach to a good, or at least a satisfactory, drawing of a technical subject per se. It seems only rarely to have occurred even to those with a special interest in technology that portrayals of technological subjects could have standards, for example precision, detail and accuracy, that applied little if at all in other kinds of visual portrayals.

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What we can learn about technological illustration in China's early history is of course especially constrained by the limits of the evidence at our disposal. Down to the Tang dynasty (618–906), the body of useful surviving images of technologies is particularly fragmentary, and for many periods and technologies even non-existent. Since only a handful of the most important and highly admired paintings or calligraphic works produced during these centuries have survived, almost all as copies,[9] we find ourselves often having to rely on a

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technological equipment was quite simple and easily constructed by experienced carpenters and other craftsmen. Where more sophisticated knowledge came into play, as with the building of large ships for example, the builders in China as elsewhere typically used no manuals (they were usually illiterate), templates or blueprints, relying instead on a broad know-how, much of which could not be put into words or pictures. Derk Bodde, *Chinese Thought, Society, and Science: The Intellectual and Social Background of Science and Technology in Pre-modern China* (Honolulu: University of Hawai'i Press, 1991), 360; George Basalla, *The Evolution of Technology* (Cambridge: Cambridge University Press, 1988), 83–84; Marshall Sahlins, *Stone Age Economics* (Chicago: Aldine, 1972), 81.

8. For incisive remarks on how the ability to design machines on paper gave the designer a much greater "perceptual span" than the traditional craftsman (e.g. he could manipulate easily all or any of the parts of a machine and even make substantial changes cost-free), see the remarks of J. Christopher Jones cited in Ken Baynes and Francis Pugh, *The Art of the Engineer* (Woodstock, NY: The Overlook Press, 1981), 11.

9. It is tempting, when referring to the period before woodblock printing, to put the word "copy" in quotation marks. Close copies made by tracing seem even after the early and essential invention of paper to have been the rare exception; most often, the "copies" are freehand renderings that can vary greatly in their fidelity to the original.

frustratingly small number of stone carvings, cave paintings, decorations on objects, and other non-manuscript sources.[10]

After the appearance and the spread of woodblock printing in the seventh and following centuries, the situation changed. Much larger numbers of illustrations, especially in the form of outline drawings, were produced and many have survived down to the present. On the other hand, a survey of these illustrations leads quickly to the realization that this abundance is partly illusory. Although constituting the surviving product of something over a thousand years, they equal in quantity far less, it would seem, than what we have just from sixteenth-century Europe with its flood of illustrated books on all kinds of technology.[11] There is also the problem of duplication: a significant proportion of what we have today on the Chinese side consists of more or less close copies of earlier illustrations (though one can of course sometimes learn important things from even small discrepancies). Finally, most of the surviving illustrations come from a relatively limited number of printed works. Though manuscripts continued to be produced in considerable numbers well into the Ming,[12] there is no surviving Chinese parallel to, for example, the manuscripts of a Mariano Taccola in the earlier part of the fifteenth century or the notebooks of Leonardo da Vinci from its end.[13] Nor do *any* of the drawings that have survived seem to have been produced by craftsmen/artisans/technicians in the course of their activities.[14] Consequently, the body of surviving

10. Repeatedly we face the danger of being led astray by odd bits of evidence that may or may not be accurate or representative. The many frescoes in the Buddhist temple-caves of Dunhuang, for example, are hardly rich in technological subjects but they do contain a fair number of illustrations of boats. Nevertheless, these illustrations are as likely to mislead as to provide usable information for the historian of technology. See Joseph Needham, Wang Ling and Lu Gwei-djen, "Physics and Physical Technology: Civil Engineering and Nautics," in Joseph Needham (ed.), *Science and Civilisation in China (SCC),* vol. 4, part 3 (Cambridge: Cambridge University Press, 1971), Fig. 968 (Pl. CDIII) and 455–56.

11. Samuel Y. Edgerton, Jr. "The Renaissance Development of Scientific Illustration," in John W. Shirley and F. David Hoeniger (eds.), *Science and the Arts in the Renaissance* (Washington, DC: Folger Shakespeare Library; London: Associated University Presses, 1985), 184. Estimates suggest that between five and ten thousand European drawings of machines and machine parts survive just from the period 1400–1700; Lefèvre, *Picturing Machines*, 13. Andrea Matthies, for her research on artistic portrayals of building construction in Europe, was able to assemble 339 images of building sites dating from the twelfth to the beginning of the sixteenth century (in contrast to a mere handful of Chinese portrayals pre-1600 and not very many after that either); they contain twenty-nine portrayals of treadmills or windlasses and eighteen pictures of wheelbarrows. Andrea L. Matthies, "Medieval Treadwheels: Artists' Views of Building Construction," *TC* 33.3 (July 1992), 513 and 545.

12. Cynthia J. Brokaw, "On the History of the Book in China," in Cynthia J. Brokaw and Kai-wing Chow (eds.), *Printing and Book Culture in Late Imperial China* (Berkeley: University of California Press, 2005), 16.

13. For a categorization of early modern European sources for machine drawings, nearly all of which have no counterparts in China, see Lefèvre, *Picturing Machines*, 14. Where the illustrations came from inevitably influenced their character. To take just one example, Leonardo's drawing style has been described as "highly personal, idiosyncratic and fundamentally inimitable"; Baynes and Pugh, *The Art of the Engineer*, 29. None of those adjectives apply very well to any Chinese illustrations of technology in traditional times.

14. By one reasonable definition of technical drawings as the drawings, sketches, etc. made by technicians for their professional purposes (Lefèvre, *Picturing Machines*, 2 and 13), we have no "technical drawings" surviving from traditional China. I therefore generally avoid this term. That does not mean, however, that I accept that no technical drawings were made even in early times. Quite the contrary: see, for example, the section in

evidence offers only a very imperfect representation of the totality of Chinese efforts to picture technology in traditional times.

The nature of the surviving evidence thus precludes any attempt here to give equal attention to all kinds of surviving images of technology. Even without the evidential constraints, drawings of mechanical technology would in any case have drawn special attention in our investigation, not least because mechanisms in all their variety and increasing complexity have posed particular challenges for the draftsmen who would portray them accurately and comprehensibly. They thus have a special intrinsic interest. Moreover, drawings of machines and mechanical devices also had a special capacity to provide information that could not be conveyed in words. This helps account for the relatively larger number of drawings of mechanisms or their components that have survived. We will try, however, not to slight other kinds of images that help supplement what we would be able to say solely on the basis of illustrations of mechanisms. Certain kinds of agricultural drawings as well as architectural depictions provide good examples.[15] Especially in earlier periods, they are relatively well represented among the surviving images and related texts. Moreover, they sometimes pioneered interesting advances in drawing techniques, some of which were later taken up in illustrations of other technologies.

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The history of premodern Chinese portrayals of technology divides rather well into two periods. During the first, from earliest times down to the Song (960–1279) and Yuan (1279–1368) dynasties, a growing ability of Chinese artists to portray technological subjects with greater clarity and accuracy went hand-in-hand with advances in verisimilitude that marked Chinese painting generally. Then, in the following centuries, much of the most prestigious Chinese graphic art turned away from the pursuit of realism. In the Ming (1368–1644) and Qing (1644–1911) periods, Chinese painters commonly eschewed techniques that might have led to the more accurate and effective portrayal of technological subjects. How and why this happened constitutes a major focus of this book.

Since the length and complexity of the story has led us to adopt an essentially chronological approach, this has meant that there were times when discussion of certain topics could not be treated fully in one place and had to be divided among two or more chapters. In other cases, chronological considerations have led to the grouping of rather disparate

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Chapter 2 on "Models, Automata and Technological Drawings." Nor am I as convinced as Lefèvre that there were no technical drawings in Europe prior to the construction of the Gothic cathedrals; he himself seems to imply otherwise when he writes that *"[a]lmost all of the crafts* performed their professional tasks without drawings." (my italics) Lefèvre, *Picturing Technology*, 2.

15. Interestingly, for Albrecht Dürer, "construction sites were the places where drawing was practiced at its highest level." Cited in Filippo Camerota, "Renaissance Descriptive Geometry: The Codification of Drawing Methods," in Lefèvre, *Picturing Machines*, 200. We shall discuss in Chapter 3 why this was *not* the case at Chinese construction sites.

topics in a given chapter. What follows then will be an attempt to provide a kind of roadmap indicating how many of the most important topics and themes fit into our chronological framework. Readers will also notice a certain imbalance in the story as it is told here, with much more space devoted to the Song and post-Song periods than to what came before. To a great extent, this reflects how much less we know about the earlier period because of the dearth of surviving evidence. But it also results from the fact that one of our overriding questions — why illustrations of technology displayed so little further development in the post-Song centuries — can and must be answered in some detail on the basis of the more extensive evidence for that period and the consequent scholarly attention that has been devoted to it.

Following this introduction, Chapter 1 takes up the appearance and evolution of early graphics in China. We introduce some of the first surviving Chinese efforts to portray technical subjects and the context out of which they arose. In particular, we shall direct our attention to the emergence of certain ideas — a preference for generality over specificity, great emphasis on the moral and persuasive power of pictures — that had an enduring influence on the role illustrations later came to play not only in the graphic arts and in the illustration of technology but also in Chinese culture generally.

In this chapter, we also pay special attention to the unique importance of early illustrations of farming and clothmaking in China. To be sure, the paucity of surviving illustrations from this early period will force us to defer until later our discussion of questions such as the extent to which the kinds of illustrations produced were influenced by the mechanically rather simple technology of agriculture or by the sometimes considerably more complex technology of clothmaking. Here, however, the mainly textual evidence enables us to identify the emergence of clear traditions governing how and why agricultural activities were to be portrayed and to note the social and political basis for a phenomenon unique to China: an extensive body of illustrations depicting agricultural work by peasant farmers but produced by artists from an elite background and reflecting their values.

Chapter 2 deals with the period mainly from the third to the tenth centuries when the continuing paucity of surviving illustrations of technical subjects obliges us to examine general developments in painting in order to tease out what they might be able to add to our knowledge of technical depictions at this time. We shall see that, during these centuries, Chinese painting remained generally committed to realistic narrative representations, with many artists devoted to creating greater verisimilitude in their paintings. But just as the prevailing aesthetic values were encouraging greater realism in painting and drawing, the almost exclusive use of the Chinese brush for visual representations may have impeded the development of certain representational techniques. Moreover, while the invention of woodblock printing toward the end of this period made possible a much wider reproduction and circulation of illustrations, it was a technology that also contained in itself the potential to inhibit advances in illustration techniques.

Chapter 3 brings us to the Song (960–1279) and Yuan (1279–1368) periods, widely regarded as the highpoint in traditional times of both Chinese technological creativity as well as the visual portrayal of technology. Before turning to five landmark works from the eleventh to the fourteenth centuries, each of which represents a new level of achievement in the graphic presentation of technology, we examine one style or technique of Chinese painting, "ruled-line painting" (*jiehua* 界畫), which is the only important non-freehand style of drawing and painting ever developed in China and which, more than any other style, also displayed remarkable potential for the portrayal of technological subjects. We shall see how certain artists realized this potential but also how certain impediments prevented broader use and enhancement of these techniques. We shall also consider the complex role of a government that often supported and promoted technology but also, in its efforts to keep control over certain technologies firmly in its own hands, could serve as a brake on technology itself as well as on its depiction.

The earliest of our landmark works is a military manual, the *Collection of the Most Important Military Techniques*, compiled by imperial order and dating from 1044. As with most early illustrated works on technology, we no longer have its original illustrations and must therefore constantly make judgments, which will always remain tentative, about how closely one or another later copy approaches the original. Nevertheless, it does seem that techniques seen in later versions of the illustrations that would have been "cutting edge" for the early Song period, techniques such as front and rear elevation drawings as well as component parts and assembly drawings, may well have been used in the Song originals. None of them, in any case, were unique to this work.

In addition to technology used for the production of things, some of the most sophisticated technology in China, as in other early civilizations, aimed at the production of information and knowledge. Astronomy and astrology provide the most remarkable examples. The devising of sophisticated astronomical measuring instruments was well underway as early as the Former Han (202 BCE–9 CE). Though we lack confirming evidence, it appears highly likely that something like working drawings must have, from very early times, aided in the construction of these instruments. In any case, such drawings were reaching ever higher levels of sophistication by the Tang (seventh to ninth centuries) and giving birth to a drawing tradition that made possible at the end of the eleventh century the production of one of the greatest masterpieces of traditional Chinese technical illustration, the *New Armillary Sphere and Celestial Globe System Essentials* of Su Song. Its sixty-one illustrations, focusing exclusively on the workings of a single complicated mechanism, display a number of breakthroughs. As in the *Military Techniques*, some were assembly or sub-assembly drawings, but rendered in greater detail than in the earlier work. Many made effective use of labels within the picture, and some even provided answers to the problem of revealing the workings of those hidden parts of a machine that cannot ordinarily be seen.

It is impossible to imagine the *System Essentials* (or Su Song's clock tower itself, which it described) as having been produced without all-out support by the government. One can say much the same for another, almost exactly contemporaneous, masterpiece, the *Building Standards* of Li Jie. Li, like Su, was an official in the central government and was assigned to codify the practices used in the building of various kinds of government edifices. Although it was meant as a handbook for officials who would be supervising government projects and consequently devoted a great deal of discussion to subjects such as the costs of materials and labor as well as how to avoid problems such as pilferage, it was also unique in the detail, accuracy and comprehensiveness with which it depicted actual building practice. It has enabled scholars to reconstruct building techniques in the Song with a thoroughness that would be inconceivable were they confined to examining the very few buildings that survive from that period or later writings on building techniques, none of which ever came close to matching the thoroughness of the *Building Standards*.

Given the importance of agriculture in Chinese life and technology, it should not surprise us that not one but two of our masterworks from the Song-Yuan period focus on agriculture (and the closely-associated manufacturing of cloth, especially but not exclusively silk). The first, dating from the first half of the thirteenth century, is the *Pictures of Tilling and Weaving* by Lou Shu. In two scrolls, Lou presented some twenty-one scenes dealing with agriculture and another twenty-four dealing with silk production. This is the first example we know of in China that recorded extended processes of production in individual illustrations of their successive steps. Lou also included with each scene a lyric connected (albeit sometimes tenuously) with what was happening in the illustration. Just what importance Lou assigned to the portrayal of farming and silkmaking technology is an extremely complex question, as is his motivation for creating these scrolls. Current scholarly opinion tends to place a great deal of emphasis on moral/ideological points Lou was supposedly attempting to make. However that may be, these works had a powerful influence on how agriculture came to be portrayed for centuries afterwards. They are also typical of most other portrayals of farming activities, where the technology in use seldom occupied center stage.

The second of these two major agricultural works was Wang Zhen's *Agricultural Treatise* which dates from the beginning of the fourteenth century. It not only pioneered a new approach to written descriptions of technology but also displays the creative experimentation that marked the best visual portrayals of technology at this time. The treatise can be seen as a kind of culmination of the agricultural handbooks officials had been compiling on their own initiative since the Song in an effort to promote better farming methods. But contrary to the earlier handbooks, the *Treatise* is the first surviving handbook to contain illustrations. And it provides them in unique abundance with almost three hundred drawings and diagrams relating to the practice of agriculture. Moreover, Wang's primary focus on the actual technology in use reveals itself in how often he presents the tools and machines by themselves without landscape settings or people using them. In other words, some painterly elements that are prominent in Lou Shu's scrolls are more sparingly employed here. When farmers and workers do make an appearance, they frequently are portrayed in such a way as to contribute to a better comprehension of the technology.[16] It is productive activities and not aesthetic or moral values that dominate. Here Wang was truly unique. No one who came after him ever wrote such detailed discussions and provided such profuse illustrations of farming equipment. When these kinds of illustrations appear in later works, chances are that they were borrowed from Wang's *Treatise*, either directly or through later copies.

The Song and Yuan dynasties witnessed not only unprecedented achievements in technological illustration but also a major reorientation of much of Chinese life and culture, the subject we turn to in Chapter 4. Many of these developments are reflected in altered thinking about just what the aims of painting should be. By the end of the eleventh century, a new scholar-official elite (often referred to in English as the "literati") now dominated the political and cultural scene in China. To a degree unique among ruling elites anywhere, many of them took up painting as one expression of their cultural superiority. In so doing, they frequently subscribed to a view that rejected the importance of realistic representation in favor of painting that supposedly enabled highly cultivated artists of superior character to give expression to their moral and intellectual pre-eminence. In place of technical skill, many literati critics and connoisseurs even came to admire a certain clumsiness or awkwardness which they held to be harder to achieve than mere skill. These ideas, which influenced not only painting but also other kinds of graphic art, ran directly counter to the kind of exactness and accuracy that make portrayals of technology informative. At the same time, a general consensus on a relatively limited repertoire of subjects suitable for this kind of painting, above all subjects that were easy to paint and could carry significant symbolic baggage, also served to discourage realistic portrayals of technology.

The new approach to painting was further inspired by a vision of the world and the cosmos that was perhaps the most original component of resurgent Confucianism in the Song. It too undoubtedly inhibited to at least some extent both the further development of technology itself as well as efforts to get it accurately onto paper or silk. Its focus on the supposed principles or ideas (*li* 理) of which all things were seen to be manifestations, together with a belief that all objects of a given class shared the same principle, encouraged the scholar-painter to seek to capture the commonalities that united objects rather than to portray those objects in all their detailed individuality. It was only, in the famous words of Su Shi (1037–1101), "a superior man of outstanding talent" who could achieve this in his painting. Mere accurate representations were the work of craftsmen and professionals, who might be highly skilled but who worked according to lower standards and did not deserve mention in the same breath with scholar-painters.

This last point alerts us that there can be a danger of overstating the negative effects of developments in one kind of painting, that by scholar-amateurs, on technological portrayals in general. Beyond the rarefied circles in which most scholarly painting was done, images of technology survive in paintings by professional artists who may have been influenced by the prevailing standards of literati painting, but who gave them less than unconditional

16. This is especially true for the illustrations of sericulture.

adherence. Unfortunately, these works have survived in relatively small numbers compared to the literati paintings prized, collected and commented on by critics and connoisseurs over the centuries since. Moreover, in those that have survived, one detects little inclination and certainly not any general trend toward more effective portrayals of technology.

Because of a great upsurge in book printing during the sixteenth century, however, by far most of the technological depictions we have from the Ming and Qing dynasties are not paintings but rather outline drawings in the form of book illustrations. Inevitably, the demands and the potential of these drawings differed from those of painting. Some of these differences could impact negatively on the portrayal of technology. For example, it was intrinsically more difficult to include fine details in a woodcut than in a painting,[17] all the more because the Chinese regularly used softer plankwood for their blocks instead of harder end-grain wood that would have permitted finer lines and hence finer detail.[18] On the other hand, given a growing and broader readership and the consequent production of many books that focused on providing practical information and entertainment for ordinary readers, realistic representation played a greater role in book illustrations than in paintings. At the same time, in the often highly competitive world of Ming and Qing book publishing, the quality of illustrations often suffered from publishers' efforts to hold down costs. Very crude illustrations of technology such as those found in surviving household manuals that aimed at the lower end of the market provide abundant examples of this process at work. More generally, it is probably fair to say that most of the technological subjects appearing in book illustrations, like most of those in paintings, were treated cursorily and conventionally. As long as enough information was included to make the subjects recognizable, few readers seem to have minded.

Nonetheless, as we discuss in Chapter 5, it was in this environment that there appeared, in 1637, a remarkable compendium entitled *The Exploitation of the Works of Nature* whose author, Song Yingxing, attempted for the first time in Chinese history to provide an overview of most of Chinese productive technology. Its textual descriptions as well as its profuse illustrations — 122 line drawings in the original edition — are our best single source for information on traditional Chinese technology. This is especially true both because traditional Chinese technology had largely reached its maturity by the early seventeenth century and because no other author before the twentieth century ever again attempted to present so comprehensive an overview of that technology.

17. Paintings intended to be reproduced by woodblock printing quite likely were often intentionally simplified or schematized to make the carving of the blocks easier; Liu Heping, "*The Water Mill* and Northern Song Imperial Patronage of Art, Commerce, and Science," *The Art Bulletin* 84.4 (December 2002), 574.

18. Lucille Chia, "Text and *tu* in Context; Reading the Illustrated Page in Chinese Blockprinted Books," in Jean-Pierre Drège (ed.), *Dossier: Texte et image dans le livre illustré chinois*. Special section in *Bulletin de l'École française d'Extreme-Orient* 89 (2002), 243. In Europe, the limits on the ability of woodblock to reproduce minute details were reached already in the mid-sixteenth century; William M. Ivins, *Prints and Visual Communication* (Cambridge, MA: Harvard University Press), 47; Michela Bussotti, "Woodcut Illustration: A General Outline," in Francesca Bray, Vera Dorofeeva-Lichtmann and George Métailié (eds.), *Graphics and Text in the Production of Technical Knowledge in China: The Warp and the Weft* (Leiden and Boston: Brill, 2007), 469.

The richness of this work together with the availability by the late Ming of extensive materials on a great number of topics that relate to its composition enable us to explore in greater depth than possible for earlier works certain questions crucial to our understanding of how the illustrating of a work such as Song's was carried out and why the illustrations took the form they did. Moreover, the illustrations are even more useful because, for every one of the illustrations of the original edition, we have one or more later versions, typically copies, of the same subject. Examining the similarities and differences in the various versions can tell us a great deal about the capabilities and the limitations of Chinese illustration of technology from the seventeenth to the nineteenth centuries.

Our final chapter takes up developments in the Qing period, above all the fascinating story of the Jesuit efforts to introduce into China the most up-to-date painting and drawing techniques from Europe (along with much else from Renaissance culture), and Chinese responses to those efforts. Two outstanding figures will help flesh out this story: Wang Zheng, the first Chinese to attempt to engage seriously with Renaissance mechanics, and the painter Jiao Bingzhen who produced under imperial sponsorship a remarkable new series of illustrations for the *Pictures of Tilling and Weaving* (Chapter 3) that were very much influenced by the new Western techniques, especially linear perspective. Our examination of certain developments in Renaissance Europe that found little or no resonance in China will help us to understand the difficulties Wang encountered in trying to get an intellectual grip on both the ideas and the illustrations of the new science of mechanics as well as the limited influence Jiao's and similar efforts had on Chinese painting practice. In the latter case, the new techniques were met with considerable skepticism as to their value or usefulness even when they enjoyed a certain admiration for their cleverness.

Finally, we shall also examine a kind of last flowering of realism in traditional Chinese painting, the great revival of *jiehua* painting during the Qing. *Jiehua*, as discussed in Chapter 3, was the style of painting that had most in common with the outline techniques of book illustration. Though it displayed many qualities such as precision and attention to details that were essential to good technical illustration, it ultimately failed, probably because of its almost exclusive concern with architectural images, to exert any broad influence on Chinese illustration techniques at the end of the imperial period.

The larger picture that will emerge from this and the previous chapter is that illustrations, sometimes devoted to or including technical subjects, were a vibrant and pervasive segment of China's flourishing book publishing industry from the fifteenth to the nineteenth centuries. Nevertheless, that vitality did not generally express itself in the exploration of new directions in the techniques of technical drawing. This will lead us to a brief closing discussion of possible causal links — in both directions — between technological illustrations and the advance or stagnation of technology.

Closing Comments

By way of closing, we focus below on a number of themes that are of paramount importance for understanding the role played by portrayals of technology in traditional Chinese culture.

Non-technological Aims in Portrayals of Technology

The introduction to this study emphasized that one of the most important assumptions to jettison when considering premodern Chinese depictions of technology is that they responded primarily to what we would identify as "technological" needs or concerns. Whether in the form of paintings or the book illustrations that are the source of most of our surviving portrayals, pictures of technological subjects typically sought to appeal to a viewership the overwhelming majority of whom would have little or no direct experience with or special interest in the technologies portrayed. Most of these viewers would be drawn above all to pictures that were aesthetically pleasing or entertaining. It is true that these portrayals also often embodied a didactic element. But if they did so, it was one that focused not so much on providing technical information and understanding[1] as on conveying moral or ideological instruction or inspiration. Such themes might range from the importance of hard work in order to produce the necessities of daily life to the obligation of the ruler to see that living conditions throughout the land supported a harmonious social order. Well-drawn agricultural illustrations could be admired for a certain kind of "ideological efficacy" since agriculture, as we have noted, was often seen to be at the heart of a well-functioning socio-political order and even a well-ordered cosmos.[2] The dominance of non-technological aims in the illustrating of technological subjects often meant that it was left to written texts rather than to illustrations to present technological information for practical use.

There were of course exceptions. We have seen Wang Zhen's *Agricultural Treatise* as one of the most remarkable. Another example, dating possibly from the nineteenth century, involves the case of the official who tried to revive silkmaking in Shaanxi but found the accounts in standard works such as the *Can sang jiyao* 蠶桑輯要 (A summary of sericulture)

1. The kind Bert Hall discusses in "The Didactic and the Elegant."
2. As an imperial edict summarized it in BCE 111: "Agriculture is the basis of the whole world." Needham, Wang and Lu, *SCC* 4:3, 264.

and the *Bin feng guang yi* 豳風廣義 (An overview of the customs of Bin) to be too difficult for ordinary people to understand. He therefore had straightforward pictures printed that would be "understandable at a glance" (*yi mu liao ran* 一目了然).[3] Nevertheless, even in attempting to understand the illustrations of a self-consciously "technological" work such as Song Yingxing's *The Exploitation of the Works of Nature*, we do well to keep in mind that it is *our* tendency to judge the illustrations according to the accuracy and clarity with which the technologies (and especially the tools and machines) are portrayed. Most Chinese readers would as likely have judged the success of the illustrations on their ability to generate in a pleasing way a feeling for what performing this work was like, or what they would like to think it was like.[4]

Most of the portrayals of technology therefore could be and were accomplished quite adequately by artists with a less than thorough understanding of the technology involved. So long as there was little stress on precision, accuracy and verisimilitude, the portrayals did not require the talents and skills of people like the hyphenated artist-physicians, artist-engineers etc. so prominent in Renaissance Europe. Communication between scholar-artists or scholar-official artists (useful hyphenations in the Chinese context) or even professional artists and the users of technology was rare in China.[5] Thus the illustrating of technology continued to "improve" so long as such improvement was consonant with mainly aesthetic values. When they diverged, aesthetic values — very often inimical to better technological portrayals — tended to prevail. For advances in technological illustration to have continued, China would have had to produce a new kind of illustrator/designer/painter with a keen interest in technology. Such figures or even Chinese variations of them were rare to non-existent in the Chinese context.

Pre-eminence of Agriculture and Human Inputs

Agriculture as we have seen was the uniquely important Chinese productive technology. The amount of food needed to feed a large, dense population, the numbers of people involved in producing it, the sophistication of Chinese agricultural practice (drawing as it did on a vast reservoir of knowledge deriving from millennia of experience across a highly varied environment),[6] and the focus on agriculture in so much of the thinking of both the people and the government: all of this put agriculture right at the heart of Chinese life. It is

3. Wang Chaosheng, *Farming and Weaving Pictures*, 170 (169).
4. Recall the discussion of the idealizing character of many technical illustrations in Jiao Bingzhen's version of the *Pictures of Tilling and Weaving* in Chapter 6.
5. As it was generally between scholars of any kind and craftsmen. Needham, Robinson and Huang, *SCC* 7:2, 230.
6. A point that particularly struck the Jesuits in the seventeenth and eighteenth centuries was the range of considerations for determining just what kind of manure to use. Mark Elvin, "The Technology of Farming in Late-Traditional China," in Randolph Barker and Radha Sinha (eds.), *The Chinese Agricultural Economy* (Boulder: Westview Press, 1982), 13–14.

therefore hardly surprising that agriculture played a crucial role in the early development of painting in China (as discussed in Chapter 1). In later times, it also became the subject of a vast literature as well as enjoying at least quantitatively considerable preeminence in visual portrayals of technology in China.[7]

Agriculture was what one might call an organic technology. Like China's other great rural technology, the making of cloth, it dealt with the manipulation of living matter. Rather unlike clothmaking, however, its tools tended to be simple and easy to illustrate, its tasks often not amenable to the use of machinery of any complexity.[8] More important than tools and machines were care and dedication in carrying out the tasks of farming.[9] Farmers drew upon a considerable experience-based knowledge relating to soil, climate, seeds, fertilizer and water needs, much of which was intuitive and did not easily lend itself either to verbal or to visual elucidation.[10] A particularly explicit and striking example of the essential role of intuitive knowledge is found in the poem that accompanies the illustration of a draw loom in the *Pictures of Tilling and Weaving*.[11] The third line of the poem speaks of "hand and mind [working] in *obscure resonance*" to produce an intricate design; it neglects to mention the complex loom without which the task would have been impossible.

This emphasis on human skills and, often enough, strength too, may provide at least part of the explanation for less reliance than one might expect on mechanical devices even in the final centuries of the empire. The relative paucity of complicated machinery in Ming and Qing China, especially complex machines with concealed workings, shows the Chinese as distinctly less inclined to seek out mechanical solutions for technological tasks than either the Europeans or the Japanese, as we noted in Chapter 6. This tendency may have been reinforced by economic conditions in the last two dynasties. China at that time had a vast body of cheap but skilled rural labor that, despite a growing shortage of resources including wood and iron for constructing machines, was able to maintain rises in agricultural production necessary for an ever-growing population. In these conditions, using machines to substitute for labor risked increasing costs as well as lowering yields when it was precisely maximization of those yields that was needed to feed China's dense and growing population.[12]

7. There is a striking contrast here with what we find, say, in the late Middle Ages in Europe, where technical illustrations typically focused on tools and machines used in surveying, building and warfare; Knobloch, "Technische Zeichnungen," 50.
8. Elvin, "How did the Cracks Open?," 11. See also Francesca Bray's distinction between "mechanical technologies" which were typical of European farming and the "skill-oriented" technology that characterized wet-rice cultivation. Bray, *The Rice Economies: Technology and Development in Asian Societies* (Oxford: Blackwell, 1986), 7.
9. Thus, in north China, the small plots of poor peasant farmers could regularly be made to produce far better harvests through garden farming than the more extensive holdings in large estates where the same level of diligence and skill was not applied. Elvin, "Technology of Farming," 14.
10. Elvin, "Technology of Farming," 13. We should keep in mind, however, that there were some cases, as in the weeding illustrations of the *Pictures of Tilling and Weaving*, where verbal explanations could convey knowledge extremely difficult or even impossible to depict in a visual image.
11. Bray, *Technology and Gender*, 201, Fig. 14; compare Hammers, *Pictures of Tilling and Weaving*, 211.
12. For these points, the works of Mark Elvin, especially "The High Level Equilibrium Trap," "China as a

Thus we see, for example, that Chinese farmers devised a way of hulling grain by means of a water-powered stamp but commonly found it more cost-effective to do the hulling by hand-pounding or by using a foot-powered stamp.[13]

Given the de-emphasis of mechanization in so much of Chinese productive technology, it followed quite naturally that Chinese illustrations of technology, tending to reflect the actual technology in use, regularly present us with a picture of technology even in the nineteenth century in which practitioners applied knowledge, skills and muscles in place of more or less complex machines and inanimate sources of power.

Underrepresented Technologies

We can gain further insights into the strengths and weaknesses of Chinese portrayals of technology by considering a number of quite important productive activities in traditional China whose technologies are not well represented in the surviving illustrations, especially those dating from before the nineteenth century. Mining is a good example.[14] That mining did not generate more images may at first be somewhat surprising since mining was, after agriculture and clothmaking, the productive technology that engaged the largest number of laborers in traditional China.[15] But mining as practiced in premodern China was also a technology that relied much more on experiential knowledge not easily pictured than on a well-developed toolkit. Moreover, it did not, in the Chinese circumstances, invite significant mechanization: the excavation and transport of its product relied overwhelmingly on the availability of abundant supplies of cheap labor supplemented by very basic equipment that changed little over the centuries. In addition, a perennial shortage of investment capital for mining[16] further inhibited the introduction of machinery into the mines and the stimulus that might have given to mining illustrations.

Two further reasons may also help explain the paucity of mining illustrations. Chinese illustrators seem to have had special difficulty portraying an underground environment convincingly. We can compare this nineteenth-century illustration of a large underground copper mine in Yunnan (Fig. 7.1) with two examples of the far better illustrations of mine interiors Japanese painters and illustrators were capable of in the same period (Plates 15 and

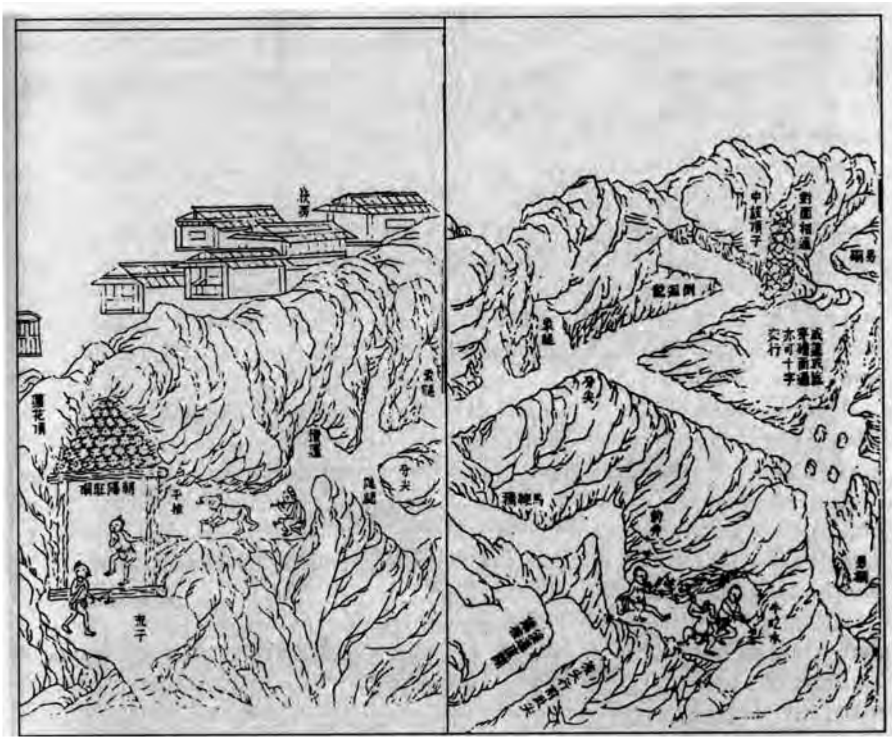
Counterfactual," and "The Technology of Farming," are indispensable.

13. Franke, *Ackerbau*, 123; 155–56n41; 157–59n49.

14. As so often, Song Yingxing's late Ming *The Exploitation of the Works of Nature* is the main exception, providing illustrations of coal mining (Sun and Sun, *T'ien-kung k'ai-wu*, 204, Fig. 11–3), silver mining (239, Fig. 14–2), digging a shaft (Sun and Sun, 243, Fig. 14–5), surface mining of iron ore (Sun and Sun, 246, Fig. 14–8), concentrating ore by washing (Sun and Sun, 249, Fig. 14–9), washing tin ore (Sun and Sun, 253, Fig. 14–11 and 254, Fig. 14–12), and gem mining (Sun and Sun, 301, Fig. 18–3 and 302, Fig. 18–4).

15. Golas, *SCC* 5:13, 1–3, 14–16. Also, in total value of its product, mining likely ranked directly behind agriculture. It is perhaps not without significance that Hommel begins his volume *China at Work* with a discussion of mining, especially coal mining.

16. Golas, *SCC* 5:13, 410–15.



7.1 Large underground copper mine in nineteenth-century Yunnan

16).[17] Finally, an instinctive aversion to mining and miners, by no means unique to China, also may well have discouraged the writing about and therefore also the picturing of mining technology.

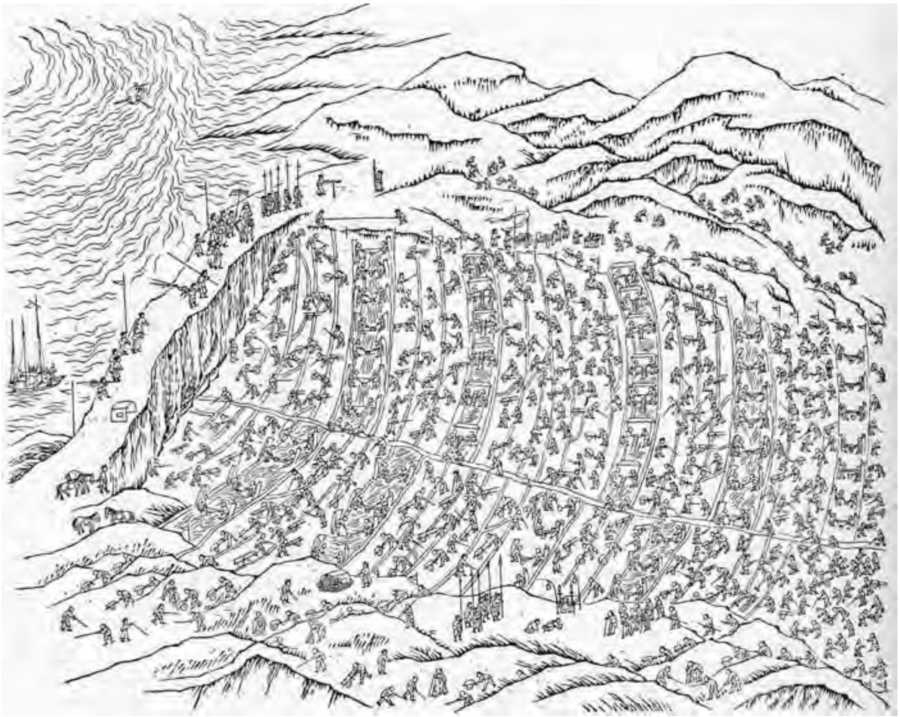
Control of water was another activity that generated much less in the way of interesting technological illustrations than might have been expected given the rich history of water control projects such as irrigation works,[18] flood control, polders, river conservancy and transport canals[19] that did so much over the centuries to modify the Chinese countryside. Such projects were often sponsored, directed and funded either by the central government or by local officials and were seen as an important part of the government's responsibility to provide for the needs and welfare of the population. They thus benefitted from the considerable resources the government had at its disposal. That we do not have more in the way of enlightening illustrations undoubtedly reflects the fact that the implements and machines

17. For a sample of European portrayals of mining from the sixteenth century, together with a succinct but superb discussion, see Lefèvre, "*Picturing Machines*."
18. Elvin provides an excellent overview and classification of irrigation techniques in "Technology of Farming," 21–24.
19. For a breathtakingly thorough overview of these activities, crowning achievements of Chinese technology that are often insufficiently recognized, see Needham and Wang, *SCC* 4:2, 330–62 and Needham, Wang and Lu, *SCC* 4:3, 211–378; a large proportion of the relevant surviving illustrations, especially those from Song Yingxing's *Tian gong kai wu*, are reproduced in these pages.

for excavation, building embankments and such tasks were generally simple and similar to those long used in other activities such as agriculture and mining. As for other knowledge and techniques more specific to hydraulic engineering such as the behavior of water flows in different conditions, these did not lend themselves well to visual portrayals. Occasionally we come across an illustration of what, right down into modern times, was more responsible than anything else for the greatest achievements of the Chinese in this technology: the unparalleled ability of Chinese officials to organize vast numbers of laborers to accomplish large, sometimes even massive, projects (Fig. 7.2).[20] This mid-nineteenth century illustration from the autobiography of an official skilled in hydraulic engineering shows the cutting of a canal by large numbers of workers using for the most part simple digging instruments, wheelbarrows, hand-swung buckets and square-pallet chain pumps. It powerfully makes the point that the best available "technology" in projects of this kind consisted mainly in the organizing of a massive labor force, which, in itself, effectively became a giant machine.

Shipbuilding was another under-reported and under-illustrated technology in traditional China. Despite the ubiquity of water transport especially in south China but also along the coast in the north, the plethora of river, lake and sea battles in China's military history, and the seven great voyages of Zheng He 鄭和 (1371–1433) in the Ming,[21] no systematic manuals on shipbuilding seem to have been published in China before nineteenth century.[22] Even one important manuscript that clearly deserves such a characterization was a product of the first half of the nineteenth century, or just possibly the late eighteenth.[23] Illustrations of nautical technology from other sources are also quite rare. Although Song Yingxing's *Exploitation of the Works of Nature* includes a fairly extensive discussion of ships, it contains only two illustrations despite the fact that many more types of ships are described in the text.[24] And just as Song's illustrations are disappointing from a technological point of view, the same tends to be true for most other surviving depictions of ships.[25] We have seen in Chapter 3 one arresting example in the warship from the important *Collection of Most Important Military Techniques* which sports three decks but no masts or sails![26] Indeed, one frequently has the feeling that portrayals of ships were done by draftsmen or artists who had little familiarity with things nautical. Partly this reflected the fact that, as in Europe, Chinese

20. Needham, Wang and Lu, *SCC* 4:3, 261–63.
21. In the years 1403–1419 at the beginning of Zheng's voyages, Chinese maritime shipyards built 2149 sea-going vessels. SCC 4:3 (Needham, Wang and Lu), 479, fn. f.
22. Needham, Wang and Lu, *SCC* 4:3, 380. This volume of SCC, pp. 379–699, is the invaluable first reference for all topics having to do with Chinese nautical technology.
23. Needham, Wang and Lu, *SCC* 4:3, 406–8, Figs. 941 and 942.
24. Sun and Sun, *T'ien-kung k'ai-wu*, 171–80. (This translation should be compared with the extensive translated segments in Needham, Wang and Lu, *SCC* 4:3, 411–16.)
25. Needham, Wang and Lu, *SCC* 4:3, 424–29. The great exceptions are, of course, the magnificent Song paintings of ships by Guo Zhongshu and Zhang Zeduan, examples of which we saw in Chapter 3. It is just our good fortune, however, that they are so revealing since the authors apparently did not create their paintings with any specifically technological purpose in mind.
26. Compare also Needham, Wang and Lu, *SCC* 4:3, 426, Fig. 949 and 691, Fig. 1051.



7.2 The cutting of a canal at Zhongmou in Jiangsu "doubtless between 1833 and 1842." Needham, Wang and Lu, *SCC* 4:3, 262, Fig. 876. In recent times such as during the Great Leap Forward in the 1950s, projects of this kind might mobilize hundreds of thousands of laborers.

shipbuilders made little use of drawings of any kind in their work. As Needham points out, even in the twentieth century, "the Chinese traditional shipwrights used no templates or blueprints, depending rather upon the skill or sureness of eye of the oldest and most experienced craftsmen."[27] Thus, although there were undoubtedly some working drawings that have not survived, perhaps even more than we might expect, it is likely that the general paucity of shipbuilding illustrations derives above all from the fact that they were not made in the first place.

Finally, there is the fascinating case of ceramics. We have here the curious phenomenon of a highly developed technology that made the Chinese for centuries world leaders for quality and quantity of ceramic production, but which has also left behind only a small body of rather undistinguished illustrations of ceramic production processes. Here, too, a number of reasons suggest themselves. To begin with, we are dealing with not only a paucity of visual materials but also of written accounts.[28] In part, this is attributable to the widespread

27. Needham, Wang and Lu, *SCC* 4:3, 413.

28. Rose Kerr and Nigel Wood, "Chemistry and Chemical Technology: Ceramic Technology," in *Science and Civilisation in China (SCC)*, ed. Rose Kerr, vol. 5, part 12 (Cambridge: Cambridge University Press, 2004), 20.

disinterest of educated Chinese in production processes.[29] Even connoisseurs deeply drawn to ceramics focused overwhelmingly on the finished product. They took little or no interest in the dirty and dusty workshops where those products were made.[30] Without accounts of how ceramic objects were produced, there was no demand for illustrations to accompany such descriptions. Before the eighteenth century, it is only in the *Exploitation of the Works of Nature* with its twenty pages of text and twelve accompanying full-page illustrations[31] that we get a serious examination of the ceramics production process.[32]

Moreover, just as in the case of agriculture, many of the most interesting and sophisticated aspects of ceramic production — selection of the best clays, mixing of glazes, firing schedules, etc. — did not lend themselves very well to illustration. Nor did the simple and largely unchanging equipment inspire artistic depictions. As we have seen so often, the quality of the objects produced owed much less to the rather simple equipment used than to the skills and knowledge, often intuitive, that the potters brought to their task. These also lay beyond visual portrayal.

The Absence of Standards for Technical Drawing

As we have more than once noted above, another obstacle to the emergence of improved portrayals of technological subjects in China was the continuing absence down to the Ming and Qing periods of any generally accepted norms for what constituted appropriate technical illustrations. This situation contrasts dramatically with the more or less well-defined schools of painting and general book illustration.[33] Of course, one should not exaggerate. Dieter Kuhn has argued that the illustrations of the successive editions of Wang Zhen's *Agricultural Treatise* and of Lou Shu's *Pictures of Tilling and Weaving* display a "pictorial continuity" (*bildnerische Kontinuität*) and that errors transmitted over succeeding editions are "most convincing proof of a tradition."[34] I would suggest two caveats, however: first, most of the continuity in the illustrations resides in the subjects treated and much less in any drawing styles and techniques specifically identified with technological portrayals; second, apparent stylistic continuities surely derived as much from skilled copying (at which many

29. Recall the comments of Song Yingxing; Sun and Sun, *T'ien-kung k'ai-wu*, xiii–xiv.
30. Kerr and Wood, *SCC* 5:12, 31 discusses this attitude in the late Ming. There were only a few notable exceptions, including the occasional literatus who actually turned his hand to working clay (31–33).
31. In the original 1637 edition; see the excellent 1959 Zhonghua shuju reprint. For the three surviving copies of the original edition, see Golas, "Like Obtaining a Great Treasure," 569 and 594n109.
32. It is worth noting that *all* the traditional illustrations of ceramic production in the magnificent Kerr/Wood volume on Chinese ceramics come from Song Yingxing's work.
33. I do not find persuasive the contention of Liu Keming and his colleagues that "engineering drawing" became a separate discipline in China in the Song-Yuan period. See Liu Keming et al., "A Brief Survey of Engineering Drawing in the Song Dynasty." Persuasive evidence to support this is simply lacking. Moreover, it is hard even to imagine that there could have been enough demand for technical illustrations to encourage artists to specialize their efforts in this area.
34. Kuhn, "Marginalie," 144; Kuhn, "Some Notes Concerning the Textile Technology," 409n5.

Chinese artisans excelled and which frequently provided the illustrations for successive printed works) as from any agreed upon standards for portraying technical subjects (for which there is no explicit evidence).

This absence of commonly accepted drafting standards was in part due also to the complete absence of professionalization, not to speak of academization, of technical knowledge in traditional China.[35] It was a situation pithily captured by Francesca Bray in her characterization of China as "a society without engineers."[36] As a result, what we might in hindsight recognize as important breakthroughs in illustration techniques tended to occur haphazardly and did not lead, especially after the Song, to substantial cumulative improvements over time. Plan drawings of the sort found in the *Building Standards* and in non-technological catalogs of archaeological objects such as the *Kaogutu* 考古圖 (Researches on archaeology with drawings) of Lü Dalin 呂大臨 (1044–93)[37] are rarely to be found in other works dealing with technological subjects.[38] No institutional mechanisms encouraged the use of improved techniques by other artists at the time or later. In the worst case, advanced drawing techniques such as the component parts drawings in the *System Essentials* were not only rarely used in later centuries but even largely forgotten.

What the artists who did illustrations of technology had in common was an approach to what constituted a good or at least a proper drawing of any kind. An important element of this approach was the use of *baimiao* or outline illustration techniques that were at best only imperfectly capable of naturalistic and precise representation of objects.[39] In those rare cases where an artist or illustrator sought not to copy but to draw an unfamiliar, complex piece of machinery using the *baimiao* technique, he inevitably tended to "generalize" the drawing, a process in which details tended to fall by the wayside.[40] This tendency was further reinforced when the artist was drawing from memory, making use of "observations stored in the mind's eye" with all their inevitable imperfections.[41]

35. The failure of the Chinese to "institutionalize" technology is a major theme of Stunkel, "Technology and Values" and is also dealt with in Vogel, "Mining Industry." One might even hypothesize that the relatively autonomous development of various technologies may be yet another reflection of the modular mode of thinking among the Chinese that Lothar Ledderose has so brilliantly brought to our attention in *Ten Thousand Things*. See also Mark Elvin, "The Man Who Saw Dragons: Science and Styles of Thinking in Xie Zhaozhe's *Fivefold Miscellany*," *The Journal of the Oriental Society of Australia* 25 & 26 (1993–94), 22: ". . . the Chinese, in science, seem to have been loners in comparison with the Europeans." Feuillet de Conches makes the same point, emphasizing that this was also true for painters. F. Feuillet de Conches, "Les peintures européens," 234–35.

36. Bray, *Technology and Gender*, 210.

37. E.g., Wu Jiming, *History of Chinese Drawing*, 40, Fig. 29.

38. One exception is a number of wheels in the *System Essentials* that might be viewed as plan drawings; Needham, Wang and de Solla Price, *Heavenly Clockwork*, 35, 38–39.

39. By their nature, *baimiao* drawings left out details as well as color, texture and techniques for modelling objects that contributed to making them appear lifelike. It was left to the reader's imagination to supply these. Hegel, *Reading Illustrated Fiction*, 325; Maeda, "*Chieh-hua*: Ruled-line Painting," 123n3.

40. See Matthies, "Medieval Treadwheels," 512, for a nice example (treadwheels) of the same thing happening in Europe.

41. Needham points out two excellent examples in his caption for an anonymous illustration of a thirteenth or

The Role of Government Workshops

When we examine the impact of the major written works dealing with technology that were encouraged by the government and even written by officials, it seems clear that works like the *Building Standards* or Wang Zhen's *Agricultural Treatise* served far more to codify existing technological practice, albeit perhaps best practice, than to encourage improvements and advances. On the other hand, the "bureaucratic" concerns that dominated these works were probably conducive on the whole to the production of illustrations that were more functional and correspondingly less influenced by aesthetic considerations.[42] Meant to help officials and others in the performance of their duties, they tend to display an unprecedented emphasis on tools, machines, instruments and components. We see this especially in the *System Essentials*, the *Building Standards* and the *Agricultural Treatise* where human beings are largely absent from the drawings instead of being right at their heart as was so often the case in drawings or paintings that pictured practical technology.

Thus the important role played by political authorities in the promotion of illustrations having to do with technology has been a recurrent theme in our story. Partly this was because government officials from very early times saw the maintenance of a harmonious society as crucially dependent on an adequately clothed, fed and housed populace. They therefore sought to encourage the production especially of essentials and, consequently, the skills and technology that contributed to it. Thus, even though most of traditional China's agricultural and textile production, for example, was in private hands, officials still frequently composed or sponsored writings that would encourage more effective production techniques.

From Shang times onward, the political authorities were also engaged in producing in government-run factories and workshops items necessary or desirable for their own personal use.[43] Mainly these were luxury products such as bronze ritual vessels, ornamented jades, lacquered utensils and silk cloth. But they also included military weapons and accoutrements, ceramic items for daily use, as well as the tools and implements needed to

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fourteenth century water-powered milling plant. Needham and Wang, *SCC* 4:2, Plate CCXLI, Fig. 627b; see also Fig. 50 above. The painter, probably painting from memory, not only confused paddle-wheels with gear-wheels but also was able to provide only a botched version of the crank, connecting-rod and piston rod combination that made up the reciprocator that worked a flour-sifter.

42. To be sure, there are many examples where one gets the impression that learning the terminology was often more important than understanding the technology. Vogel, "Important Sources of the History of Premodern Chinese Salt Production Techniques," in Hua Jueming et al. (eds.), *Study on Ancient Chinese Books and Records of Science and Technology* (Zhengzhou: Daxiang chubanshe [Elephant Press], 1998), 173. Again, this is not surprising among a thoroughly book-oriented officialdom.

43. For a very negative, but probably mostly accurate picture of at least many of the government workshops and other production facilities, focusing on the Ming period, see Xu and Wu, *Chinese Capitalism*, Chapter 3. Lothar Ledderose (*Ten Thousand Things*, 75–76) draws a distinction between "workshops" (small establishments run by a master craftsman) and "factories" (larger establishments run by managers who might or might not themselves be craftsmen). The distinction can be useful provided it is not applied too rigidly, all the more since we frequently lack the evidence to make it with much confidence.

manufacture these and other goods.[44] The Shang workshops were the predecessors of an extensive system of government production facilities that one finds in China over most of the following three thousand years and which constituted the closest thing to a "technological sector" in premodern China. Needham offers as a "provisional conclusion" that "a considerable proportion of the most advanced technologists in all ages in China were either directly employed by, or under the close supervision of, administrative authorities forming part of the central bureaucratic government."[45]

This statement, however, invites certain qualifications. First of all, it may well apply better to the situation in earlier times when, in addition to actual governmental production facilities, nobles and powerful officials acting as patrons often attracted to their entourage people with special skills in scientific/technological matters and even sometimes operated quite large production units in their residential compounds.[46] After the huge economic expansion in late Tang and Song, however, technological expertise was much more widely spread throughout the society, proportionally less monopolized by those who held political power, and more responsive to broader consumer demand. However, even in this later period, the role of the government could be decisive for broad technological advance. For example, if Kerr and Wood are correct, even in the Ming and Qing period, "massive support that central government procurement of ceramics guaranteed gave technological superiority to the whole Chinese ceramics industry."[47]

Second, even if one might generally expect a higher level of quality in the productions of government factories, workshops, arsenals etc. than was typical across Chinese society, that does not necessarily mean that these facilities were a significant force for technological innovation. Apart from certain important exceptions such as the imperial ceramics works at Jingdezhen, there is little evidence either to support or to counter such a contention. We have few surviving examples of written descriptions and even fewer drawings arising directly out of the government production environment that might alert us to innovations; insofar as they were produced, these ephemeral jottings apparently were not deemed worthy of wider distribution, either in manuscript or printed form. Only occasionally can we tell from tantalizingly laconic statements or from the products produced that innovation had taken place. Thus we learn that, at Jingdezhen, "technicians at the factory were subjected to repeated demands for innovatory products, many of them stimulated by receipt of tributary artifacts from beyond the borders of China."[48]

44. On Shang workshops in general, see David M. Keightley, "Public Work in Ancient China: A Study of Forced Labor in the Shang and Western Chou" (PhD Dissertation, Columbia University, 1969), 39–65. For silk workshops, see Dieter Kuhn, "The Silk-Workshops of the Shang Dynasty," in Li Guohao et al., *Explorations*, 397–405, which, however, includes some speculations that are very much open to question.

45. Needham and Wang, *SCC* 4:2, 20. A striking early example is the Three Seasons Tailoring Workshops of the Later Han where the workforce consisted of "several thousand male and female workers, craftsmen and artisans who were trained and skilled in all branches of the textile trade." Kuhn, "Silk Weaving," 103.

46. Needham and Wang, *SCC* 4:2, 10, 17, 26, 32, 33 and 400.

47. Kerr and Wood, *SCC* 5:12, xlvi–xlvii.

48. Kerr and Wood, *SCC* 5:12, xlvi. These demands could sometimes be so onerous that they led the potters

Finally, embedded in the very organization of government productive facilities were practices and ideas that must often have inhibited invention and innovation, even as they promoted the production of large quantities of consistently higher quality goods than may have been typical of most private producers. Many of these facilities consisted of a highly bureaucratic organization with modular production techniques that made wide use of ultra-specialized artisans who had at best very limited ability or opportunity to apply to their tasks creativity that might have led to improvements and innovations.[49] Moreover, government workshops often put considerable emphasis on standardization and holding down costs (though corruption and waste appear to have been at least as prevalent here as in other government operations[50]). These were not values likely to encourage innovation.[51]

On balance, then, government factories and workshops very possibly impeded more than they promoted technological innovation, and hence the design sketches, working drawings and the like that might have been a part of such efforts. The extent to which they encouraged the spread of technological knowledge is also open to question. The rotational workers at government works (insofar as they were not soldiers or convicts) were certainly capable of bringing home with them at the end of their tours any interesting technical knowledge that they might have picked up in their work.[52] On the other hand, in special cases such as the major government arsenals at the capital where most of the huge number of weapons to supply Chinese armies were manufactured, secrecy must have regularly played its inhibiting role both in the advancement of the technology itself and, perhaps even more, in the production of written materials that might lead to the leaking of "dangerous" knowledge to the populace.[53] Such emphasis on secrecy may also partially account for the fact that, even in eras of important advances in weaponry such as the Song, those advances seem to have occurred and spread quite slowly.

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to riot and/or destroy what they had produced. Ledderose, *Ten Thousand Things*, 86. On the other hand, abundant government resources made it possible to meet the costs of experiments and of the high rates of failure that often accompanied the development of new clays, glazes, kilns, firing techniques and the like.

49. Ledderose, *Ten Thousand Things*, 4–6, 25, 37, 84 and, especially, 48–49; 70 and 75–76. Ledderose contends that figures in the Qin First Emperor's terra-cotta army made by workers from the state factories display more stylistic uniformity — as well as a more consistent, higher quality workmanship — than those made by workers from private local workshops. See also the contrast drawn by Keightley between Chinese workshops with their modular production under bureaucratic supervision and the more individualistic ancient Greek workshops organized "around a series of acts performed by single craftsmen." Keightley, "Early Civilization in China," 19. For a fascinating example of how modular production (in this case, nose shapes) can make possible identification of different workers or work teams on a single project, see Barbieri-Low, *Artisans*, 87–88 and 89, Fig. 3–13.
50. Xu and Wu, *Chinese Capitalism*, 67.
51. Moll-Murata et al., *Chinese Handicraft Regulations*, 17 and 323.
52. Bray points out that, especially in the period up to the Song, technological skills in silk-weaving were constantly enriched throughout the country by weavers returning home from their yearly stints in the imperial workshops; Bray, *Technology and Society*, 47.
53. Or to non-Chinese on the borders who might threaten the empire. As late as the 1620s, the Manchus seem not yet to have developed the ability to manufacture gunpowder weapons. di Cosmo, "Did Guns Matter?" 141.

Overall, it may well be that the greatest positive impact of the government on the illustration of technology came not from the government workshops or factories but rather from the actual printing or subventions for printing of illustrated books that dealt with technological or related subjects. Most portrayals of technological subjects that have survived, as we have noted, are found in printed books. The political authorities — central government as well as local officials — continued active here right down to the very end of the imperial period.

Maturity or Stagnation?

It has been suggested that late imperial Chinese institutions and culture, including science, technology and art, had reached by the end of the eighteenth century "a magnificent dead end."[54] Without necessarily subscribing to quite so stark a characterization, most scholars familiar with this period of Chinese history would today agree that China's technological inventiveness and innovation declined substantially in Ming and Qing China even as the economy from the sixteenth to the eighteenth centuries underwent vigorous growth. Particularly relevant for our purposes is the fact that Chinese printing, right down to the nineteenth and twentieth centuries, remained an unmechanized handicraft industry using techniques little changed for over a millennium.[55] This could hardly be more different than the situation in Europe where, by the late sixteenth century, copper engravings had largely replaced woodblock prints for illustrations. Copper engravings not only were capable of better expression of light and shade but, even more important for technological subjects, they could convey finer details. In China, book illustrations continued overwhelmingly to be produced by the woodblock process, which of course had its own advantages in that, for example, copies of illustrations for new editions could be produced easily and cheaply by artisans of average skills using well-established techniques. Chinese book illustrations thus regularly display, as noted above, a continuity that finds no counterpart in Europe.[56]

The reasons for the paucity of new developments in technology overlap to some extent with the reasons, often economic, that we have previously discussed to account for the limited spread of even quite readily available improvements, especially but not only in the area of mechanization. As in the workshops and factories, government efforts to promote the most important technology, agriculture, present a mixed record. Even when the population/land crisis of the eighteenth century had quite clearly outrun local solutions, the court and its officials, according to Francesca Bray, did not "press for sustained innovation in agriculture."[57] The operative phrase here is "press for." According to Pierre-Étienne Will, and accepted by Bray, there was a clear disconnect between government rhetoric encouraging

54. Blunden and Elvin (*Cultural Atlas of China*, 144–47) provide a superb summary discussion of the near-stasis that had come by this time to mark so much of Chinese life and thought.

55. Tsien, *SCC* 5:1, 382.

56. Chia, *Printing for Profit*, 12.

57. Bray, *Technology and Gender*, 27, fn. 45.

agriculture and efforts actually to bring about improvements. The latter failed in some measure because the government ruled out compulsion or coercion and instead tried to get its policies adopted through education and persuasion.[58] Moreover, if Bray is correct, many of the agricultural reform schemes put forth by officials in the late Ming and early Qing sought conflicting goals that could not easily be harmonized. For most officials at that time, farming and weaving were still the very basis not only of essential economic production but also of a proper social order based on household (mainly rural) productive activities that were often divided on a gender basis whereby men farmed and women produced cloth. In fact, such standards had been greatly undercut as commercialization spread and production came to be shaped increasingly by market forces. Nevertheless, the ruling elite continued to believe that it was possible to devise policies that would reform work in such a way as to restore Confucian values.[59]

Technological advance, especially in machinery that would have invited better illustration techniques, was also impeded by the fact that the Chinese, even by the beginning of the Ming, seem to have accomplished many of the most difficult innovations in the development of sophisticated mechanical applications. Or so Elvin has argued, basing himself partly on textile machinery and pointing to such breakthroughs as mechanizing hand movements, replacing human and animal with inanimate power, and devising linkages that made possible control of two or more different motions by a single power source, animate or inanimate.[60] The very success of these developments must have lessened the inclination of the Chinese to carry on further experiments, with all the costs and risks involved. For example, the Archimedian screw pump, introduced in China by the Jesuits in the early seventeenth century, had the capacity to raise as much water as up to five square-pallet chain pumps. But the difficulty and costs of constructing and maintaining it usually made it an unattractive choice for Chinese farmers who instead stayed with the familiar, relatively cheaper and either more reliable or more easily repaired pallet pumps.[61]

Of course, it is not easy to make the case that further technological advances would inevitably have led to better illustrations. As we noted earlier, there were some significant

58. Bray, *Technology and Gender*, 31, fn. 53. Sustained efforts to increase agricultural and other production must also have been undercut to some extent by the short periods local officials served in a given post.
59. Bray, "Towards a Critical History of Non-Western Technology," in Brook and Blue, *China and Historical Capitalism*, 168.
60. Elvin, "China as a Counterfactual," 108. One illustration of how complex certain machines had become by the end of the Ming is the loom described by Song Yingxing that, if he is correct, was made up of more than 1800 parts; Bray, "Towards a Critical History," 178–79, esp. fn. 57; Sun and Sun, *T'ien-kung k'ai-wu*, 55. See also Needham and Wang, *SCC* 4:2, 225.
61. Zhang Baichun, "Archimedian Mechanical Knowledge," 11–12 of 16; Brook, "The Spread of Rice Cultivation and Rice Technology," 686. Gary Hamilton and Wei-an Chang have made a further argument that the merchant-or distribution-driven economy they see in late imperial times increasingly pushed production down into rural households, leading to the *simplifying* of the technology used. Gary G. Hamilton and Wei-an Chang, "The Importance of Commerce in the Organization of China's Late Imperial Economy," in Giovanni Arrighi, Takeshi Hamashita and Mark Selden (eds.), *The Resurgence of East Asia: 500, 150 and 50 Year Perspectives* (London and New York: Routledge, 2003), 179, 180–81, 186, 203.

technological changes and improvements in agriculture between the time of Wang Zhen in the thirteenth century and that of Xu Guangqi in the early seventeenth century. Xu mentions them in his *Nongzheng quanshu* (Complete treatise on agricultural administration) but *none* are reflected in the illustrations.[62] Even the mechanical innovations that were made in Ming and Qing farming and for which we have textual evidence almost never appear in technological illustrations.[63] Nevertheless, there is no denying that a largely static technology was not likely to create an environment that encouraged improved technological depictions.

When we reverse our focus to examine the effect that stagnation in the portrayal of technology may have had on advances in technology itself, it seems highly plausible that the shortcomings so pervasive in Chinese portrayals of technology must have impeded technological inventiveness at least to some degree. A considerable body of scholarship over the last several decades has argued that images play a much greater role in our thinking processes than was once recognized. In other words, visual thinking, the manipulation of images, can often be as important or even more important than verbal thinking, the manipulation of words. Originally, it was scholars interested in the psychology of art who pioneered these investigations.[64] But the case can be made equally well for thinking about technology. Eugene Ferguson, in his remarkable study *Engineering and the Mind's Eye*, summarizes the argument:

> Many features and qualities of the objects that a technologist thinks about cannot be reduced to unambiguous verbal descriptions; therefore they are dealt with in the mind by a visual, nonverbal process. . . . It has been nonverbal thinking, by and large, that has fixed the outlines and filled in the details of our material surroundings.[65]

When one realizes, however, that the images we carry in our minds, whether or not we use them to think with, are experience-based (derived from sense impressions, mainly from our eyes but also from our ears, nose, fingers, etc.), it is obvious that different sets of experiences will lead to very different sets of mental images.[66] In the case of technology, our repertoire of images derives not only from the tools and machines we have seen and perhaps even

62. Bray, "Agricultural Illustrations," 545.

63. As Bray notes: "When it came to practical, technical matters like farming, its seems that those educated Chinese who recorded changes or improvements were satisfied with the power of words to convey material processes, and felt no need or desire to resort to graphics." Bray, "Agricultural Illustrations," 552. An example of another kind is provided by Georges Métailié who notes that the maize (corn) plant does not appear in accurate depictions until the mid-19th century, three centuries after its introduction to China! Georges Métailié, "The Representation of Plants: Engravings and Paintings," in Bray, Dorofeeva-Lichtmann and Métailié (eds.), *Graphics and Text in the Production of Technical Knowledge in China*, 493–94.

64. I am thinking, for example, of E. H. Gombrich, Rudolph Arnheim and William M. Ivins, Jr.

65. Ferguson, *Engineering and the Mind's Eye*, xi. This book is the fuller development of ideas first presented much earlier in the author's pathbreaking article, "The Mind's Eye: Nonverbal Thought in Technology," *Science* 197 (August 26, 1977), 827–36. See also Chapter 2, "Visual Thinking" in Arnold Pacey, *Meaning in Technology* (Cambridge, MA: MIT Press, 2001) and Pfaffenberger, "Social Anthropology of Technology," 507–9.

66. As in Aesop's fable of the seven blind men examining an elephant.

used, but also from illustrations, including illustrations of technological artifacts that we may or may not have experienced in reality. In the technologically explosive Renaissance, for example, the drawings of a Georgio Martini or a Leonardo da Vinci threaten to overwhelm us with their profusion of carefully drawn details. By contrast, we have seen that Chinese illustrations even in works that focused on technology regularly underplayed precision and attention to detail.[67] They therefore did little to encourage that increasingly precise kind of technological thinking that alone could promote technological advance once machines had reached a certain level of complexity. William Ivins may not be entirely correct when he argues that creating "a culture of technologies requires much harder and more accurate thinking [than building up a culture of art and philosophy]," but it seems quite clear that, in later imperial times at least, the Chinese preferred to put their best thinking into philosophy, art and other aesthetic and academic studies, to the relative neglect of technology. To this, their depictions bear witness.

67. And also precise measurement. Bodde makes the interesting suggestion that traditional Chinese instruments and machines may overall have required less accurate measurement for their construction than those of the West; Bodde, *Chinese Thought, Society and Science*, 140.

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