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The Renaissance Development of the Scientific Illustration*

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There is hardly a more familiar artifact of modern life than the so-called scientific illustration. That is, the diagram or picture in isometric or linear perspective with notations for scale and measurement which show how machines or houses or even human beings are put together and taken apart and how they work. Who, indeed, has never depended on such an illustration for assembling a Christmas bicycle or a Sears & Roebuck porch swing (not to mention for constructing an atomic reactor or preparing for open heart surgery)? So taken for granted is the ubiquitous scientific illustration that few scholars have ever sensed that it has any historical interest. Most art historians have disdained it. They have investigated scientific pictures only when drawn by great creative geniuses like Leonardo da Vinci. Otherwise, they consider the genre remarkably inimical to creativity, a mere prostitute to someone else's verbal text.

Historians of science have shown a little more curiosity, but they too tend to treat scientific pictures only as afterimages of verbal ideas. Few historians of any kind have studied the scientific illustration as a unique form of pictorial language, with its own "grammar and syntax"; that is, symbols and conventions conveying information just as do words and sentences.[1] Nor have many scholars ever applied to the scientific illustration the tools of iconology, that wonderful subdiscipline of art history which explains how pictorial symbols work, how they are derived and change in form and meaning, and most important of all, how they reveal profound truths about the society which produced them.[2]

I would like to offer here some ideas of my own about the origin and

purpose

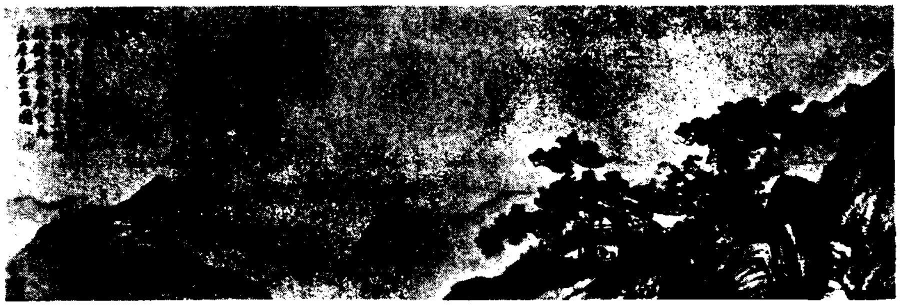
development of the scientific illustration, indeed, its special iconology in the context of Western Christian civilization at the time of the Renaissance from the fourteenth through the sixteenth centuries. What is especially interesting about this development was its steady progress toward the sheer objectification of forms without due sacrifice of esthetic quality. No other tradition of pictorial representation, in classical antiquity, in China or Islam during their artistic heyday, ever achieved such objective power. In fact, at its best, the Renaissance scientific picture gave precise information about the physical world not only without need of explanatory texts but without the need for the viewer to refer to the actual objects depicted. It may have been of no small significance to their later contributions that the first generations of "modern" scientists like Francis Bacon, Galileo, William Harvey, and Descartes, were also the first to have before them as schoolboys scientific textbooks illustrated in the new Renaissance chiaroscuro and linear perspective style. Key

Art historians of all periods and cultural specializations recognize one other quality of Western art unshared with the arts of anywhere else. This was the propensity, first noticeable in the painting of classical antiquity, to think of the picture as a fictive window or hole in the wall or book page. During the early Middle Ages, this concept was somewhat forgotten as Christian art was more influenced by oriental flatness. But suddenly, in the late thirteenth century, the picture-as-window was revived, especially in the fresco cycles celebrating the life and miracles of St. Francis of Assisi in central Italy. The startlingly sculpture-like figures in these paintings, many attributed to Giotto and enframed as if inset on a three-dimensional stage, mark the beginning of the Renaissance for art historians. Almost at the same time, the revival of the picture-as-window began to occur in the manuscript illuminations of artists working in the royal court of France.[3]

What is important to our subject here is that this revived "window" notion had inexorable consequences for Western art. It began to force the artist to think of the various details in his pictures as seen from a more or less fixed view point, as if he were looking at them from the center of an opening through a frescoed wall or illuminated page. This tendency culminated, of course, in linear perspective and in the perfection of drawing light and shadow effects; i.e., the representation of chiaroscuro in two-dimensional artistic media. A superb example of this purely Western achievement is a painting by Antonello da Messina, circa 1450–55, entitled *St. Jerome in his Study.* It is interesting to compare this masterpiece of the flowering Italian Renaissance to a Chinese painting of about the same period, that is, from the Ming Dynasty, circa 1530, by Zhou Chen called *Dreaming of Immortality in a Thatched Cottage.* What these two pictures together show is not just a difference in artistic style but a monumental difference in perception of nature itself. In the Chinese painting we see a philosopher leaning on the sill of his hut at the lower right. In his dreamy contemplation, the philosopher projects himself into the infinite landscape where we see him again, mystically levitated, as he ponders the transience of nature. Whether the artist intended this lovely mountainscape to be an

Antonello da Messina, *St. Jerome in His Study*. Trustees of the National Gallery, London.

illusion of extending space or not, he still added the inscription, at upper left, right on the picture surface without any apparent conflict in his mind that the flatness of the verbal inscription contradicted the illusion of pictorial depth. Indeed, Chinese artists never considered that they should portray nature as if



Zhou Chen, *Dreaming of Immortality in a Thatched Cottage*, ca. 1530. Freer Gallery of Art, Washington, D. C.

seen through a window, so they never felt bound by the need for consistency which the fixed viewpoint demanded of their Western counterparts. In Antonello's painting, on the other hand, St. Jerome, the quintessential Western philosopher, sits rationally in a perfectly tangible space, constructed illusionistically but according to the same geometrical principles as any actual, carpentered room. This illusionistic room is filled with light and shadow according to the exact laws of geometric optics, the same science from which were derived the principles of linear perspective. St. Jerome ponders immortality just as does the Chinese philosopher in Zhou Chen's painting, but in Western Christian thought, the ineffable is fixed and static, conforming to Euclidian rules. Indeed, the very laws of Euclidian geometry and optics, so much a part of the iconology in Antonello's picture, were believed even by the early Christian fathers to explain how God spreads his divine grace throughout the universe. Chinese philosophy, on the other hand, argued for a dynamic cosmos undergoing flux and change. The Chinese philosopher in Zhou Chen's painting contemplates this fluidity of nature as he floats in an imprecise atmosphere. His thoughts, like the lack of rationale for his levitation, transcend the fixedness of Euclidian geometry, a science which the Chinese did not known until it was introduced to them by the Jesuits in the seventeenth century. "Space" in Chinese philosophy was thus never endowed with abstract structure; that is, it was never imagined as a static medium into which objects could be fitted as if in a three-dimensional lattice-work. Chinese artists like Zhou Chen did develop sophisticated and esthetically beautiful iconological conventions for communicating the transience and rhythms of nature, but they were never interested in representing nature as a static entity. Hence, they never felt the need to develop those other iconological conventions necessary to Western art, namely convergent linear perspective and light and shadow rendering.

One of the earliest and most persistent iconological conventions to appear in European picture making, which shows how Western artists were indeed responding to the peculiar consistencies of the picture-as-window, was the curling banderole or scroll as a device for bearing verbal inscriptions. Instead of merely inscribing on the picture surface as did the Chinese artist, the Westerner felt the need to have his verbal inscription conform to the same illusionistic space structure which ordered all the other objects in the picture-as-window. In religious art especially this convention proved useful, for presenting conversations between holy figures such as the Angel Gabriel and the Virgin Mary and also for identifying prophets and saints.

In a woodcut print of the human skeleton published by Ricardus Helain of Nuremberg in 1493, we see how the illustrator borrowed the same convention for displaying the names of the various bones. To be sure, the by-now ubiquitous banderole in Renaissance art did not lend clarity to scientific pictures, and illustrators quickly returned to flat, easier-to-read labels. However, if the banderole was not an adjunct to clarity, it was to the macabre effect of the image, thereby making the print more salable and popular in the Christian context of a memento mori. Helain's diagram is a good example showing the ease with which Renaissance artists could apply the iconography of Christianity to secular science. Since earliest times Christian art had been didactic in purpose, like no other artistic tradition uninfluenced by the West has ever been. Helain's skeleton indicates how a stock Christian motif could be reenlisted in scientific service with little change in didactic intent. By knowing the names of the bones in his body, the good Christian should better appreciate his own mortality and inevitable fate.

banderole

The greatest impetus to scientific illustration during the Renaissance, however, came from yet another peculiarity of Western European culture. This was the special profession of *ingegnere*, best translated into modern English as "artisan-engineer." Both Filippo Brunelleschi, the architect, and Leonardo da Vinci, the painter, considered themselves as *ingegneri* first and "artists" in our more familiar self-expressive sense only secondarily. The profession of *ingegnere* was much honored in the Renaissance because it descended from a venerable classical tradition, from Archimedes, Philon, and Hero of Alexandria.[4] In fact, the legends of Archimedes never even went out of fashion during the Middle Ages as Marshall Clagett has shown.[5] In the thirteenth century, the Archimedean tradition was associated with the construction of Gothic churches, as is evident in the surviving notebooks of Villard d'Honnecourt, the Picard artisan-engineer who may have worked at the Cathedral of Rheims. Kept alive in Villard's drawings was also the ancient fascination for gear-driven automata, toylike machines powered by wind, water, or animal.[6]

Yet another attitude encouraging the renascence of Archimedean tradition was what we may call the "crusade mentality" of medieval Christian Europe. Certainly, fear of the Turk was one of the foremost "red herrings" of European politics of the time, and the desire to retrieve the Holy Land became an archetype imbedded in the European imagination to this day. As the Roman popes continually urged the sending of expeditionary armies against Islam, Christian princes began assiduously to patronize military science, even if they had little enthusiasm for crusading and much more for acquiring the lands of their own Christian neighbors. In response to these politics, many ambitious artisan-engineers found employment at court serving as military advisors, instructing

Ricardus Helain,
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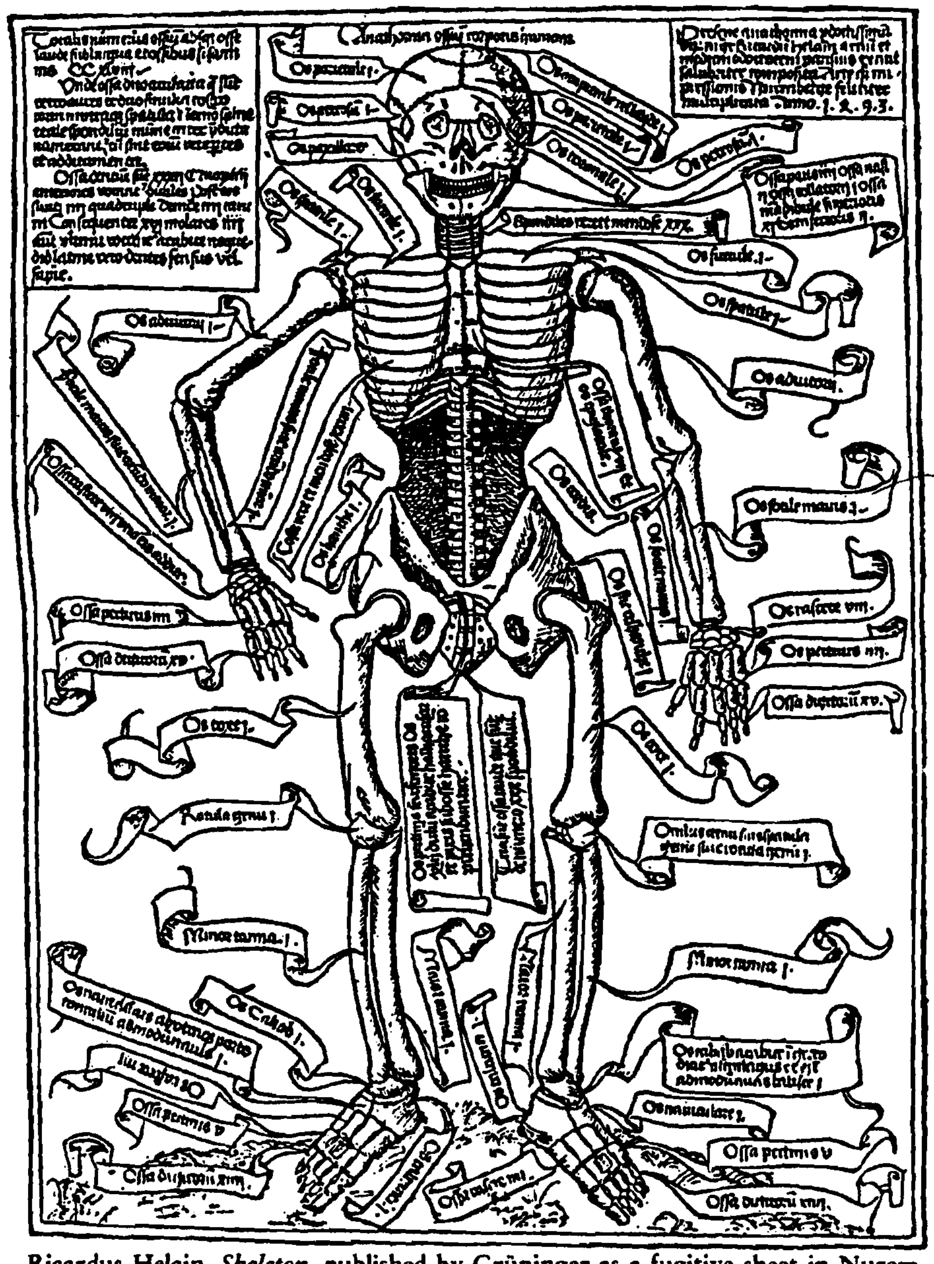

banderole for Annunciation Scenes

Ricardus Helain, *Skeleton*, published by Grüninger as a fugitive sheet in Nuremberg, 1493.

their lords on how to build offensive and defensive weapons and also hydraulic machinery, mills, pontoon bridges, and all other needs for an army on the march and fighting in a hostile environment.

A good example of this sort of patronage is that of King Philip VI of France for Guido da Vigevano, Italian engineer and physican during the mid-trecento. Guido wrote two treatises, the first dedicated to the king in 1335 called *Texaurus Regis Francie acquisicionis terre sancte* . . . , or "Treasury of the King of France for the Recovery of the Holy Land," in which are descriptions and pictures of military machines.[7] The second treatise is entitled simply *Anathomia* and was written about ten years later.[8] It also contains a handsome set of colored illustrations concerned with medical practice. As one may quickly note, each of the two examples shown here seems to be drawn by a different hand. Guido, in spite of his diverse talents, was not an artist and probably sent out his texts to be illustrated by local manuscript illuminators. The artist of the illustration from the *Texaurus* has tried to follow Guido's instructions for designing a mobile assault tower. However, he had difficulty in showing the complex crank, gear, and wheel mechanism which propelled the tower. Since he had no ready convention at hand for depicting how gears intermesh or the way wheels turn on perpendicular axles, he resorted to what some perceptual psychologists today would term a "split-view" interpretation. He represented all the details of the machine as if seen each from its most characteristic aspect. Wheels, axles, and gears thus appear to be collapsed on one another, so that the essential mechanical feature of this machine, the transmission of power across right angles, is impossible to discern from the picture. Modern psychologists have often noted that this form of "naive" representation is frequent among so-called primitive peoples and even children.[9]

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The artist of Guido's anatomical diagram, however, seemed to possess a more sophisticated sense of how to render the third dimension. Here he showed a full-length view of a cadaver with a degree of naturalism almost befitting the contemporaneous Giotto school in Italy. What is especially noteworthy is the detail of the abdomen, which the artist displayed as if the skin were cut and pulled apart like open doors. This picture introduced a number of others in the text showing the same figure with its various internal organs exposed. Guido's artist was trying to make his human figure intelligible as a hollow cylinder. He needed a convention by which the viewer could be convinced that he was looking beyond an external surface and into the concave hollow which contained the visceral organs. This artist, in fact, has anticipated the "cutaway view" which today everyone, even school children, take for granted in textbook explanatory diagrams (see p. 176).

There are probably hundreds of such artisan-engineer manuscripts still extant in libraries throughout the world. Some are beautifully illustrated, some crudely, and some not at all, but it must be said that all the illustrations from manuscripts before the Renaissance are in the "naive" category, uniformly lacking in perspective naturalism. Few even show much perception of light and shadow modeling.

Indeed, not until about the middle of the fifteenth century in Italy do we find any artisan-engineers who apply "realistic" artistic techniques and conventions. This is only natural because linear perspective and chiaroscuro rendering were both products of the Italian Renaissance. The introduction of linear per-

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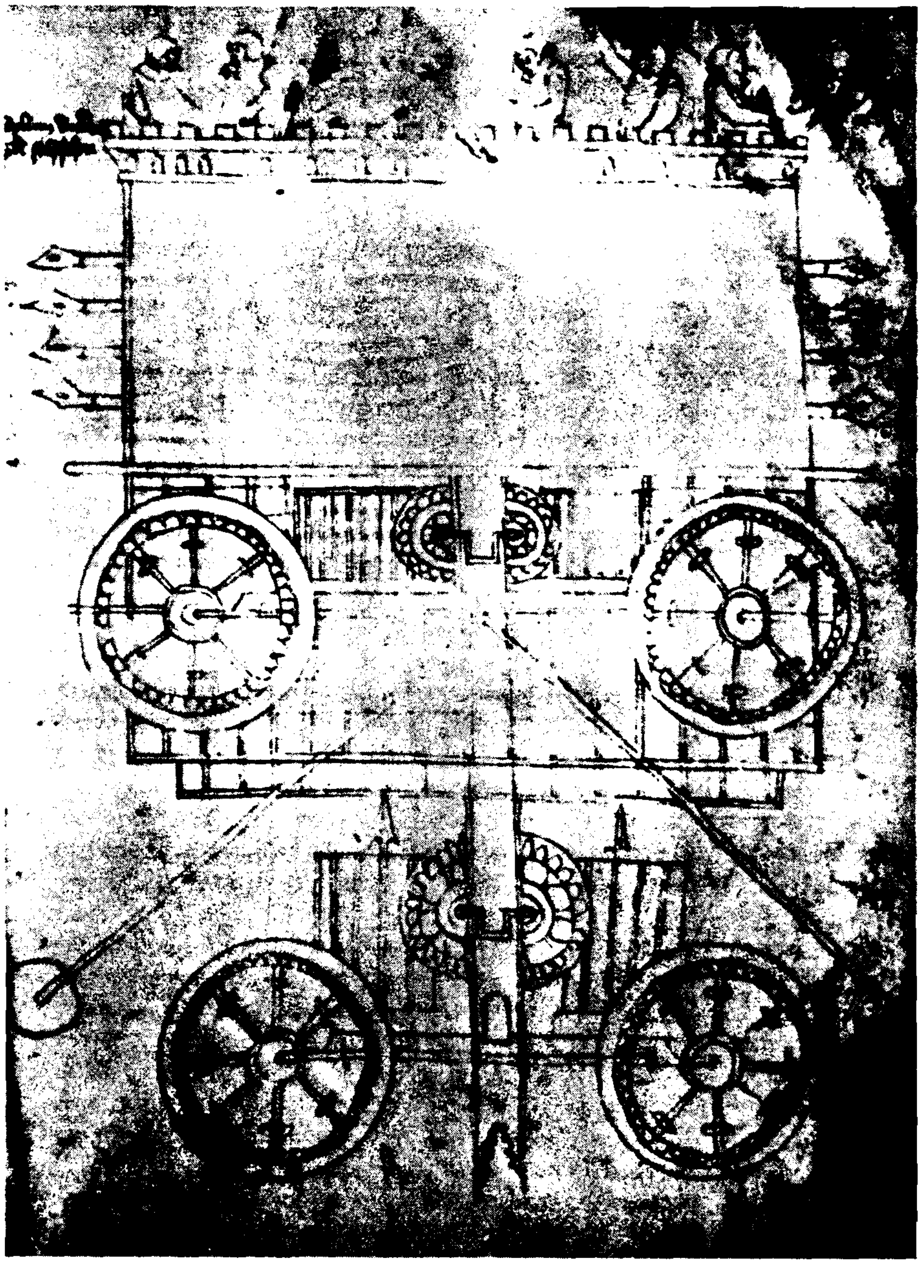
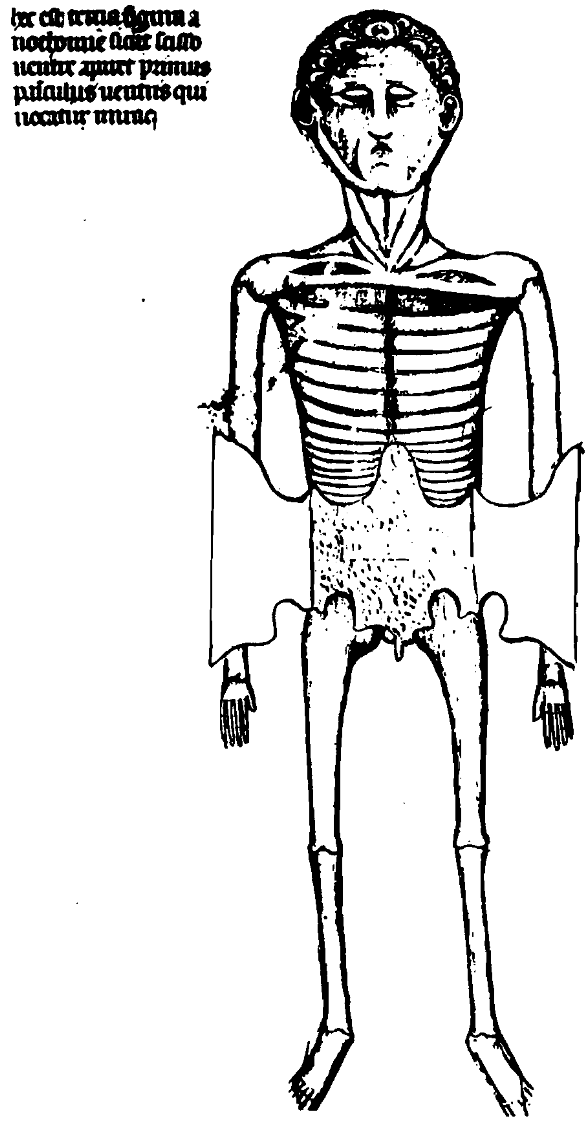


Drawing for a Mobile Assault Tower, from the *Texaurus* of Guido da Vigevano, MS. Lat. 11015, Bibliothèque Nationale, Paris.



Drawing of a Cadaver from Guido da Vigevano, *Anothomia*. MS. 334, Musée Condé, Chantilly.

spective in particular can be directly traced to the experiments of one artisan-engineer, Filippo Brunelleschi, better known for his designing of the great dome over the Florentine Duomo completed in 1436. Brunelleschi himself left us not one single drawing of any sort. Whatever notebooks he may have kept, illustrated or not, have disappeared. We only know of his exploits through the testimony of contemporaries. Fortunately, one of these did keep illustrated notebooks which are not only extant but give evidence in their own right of the

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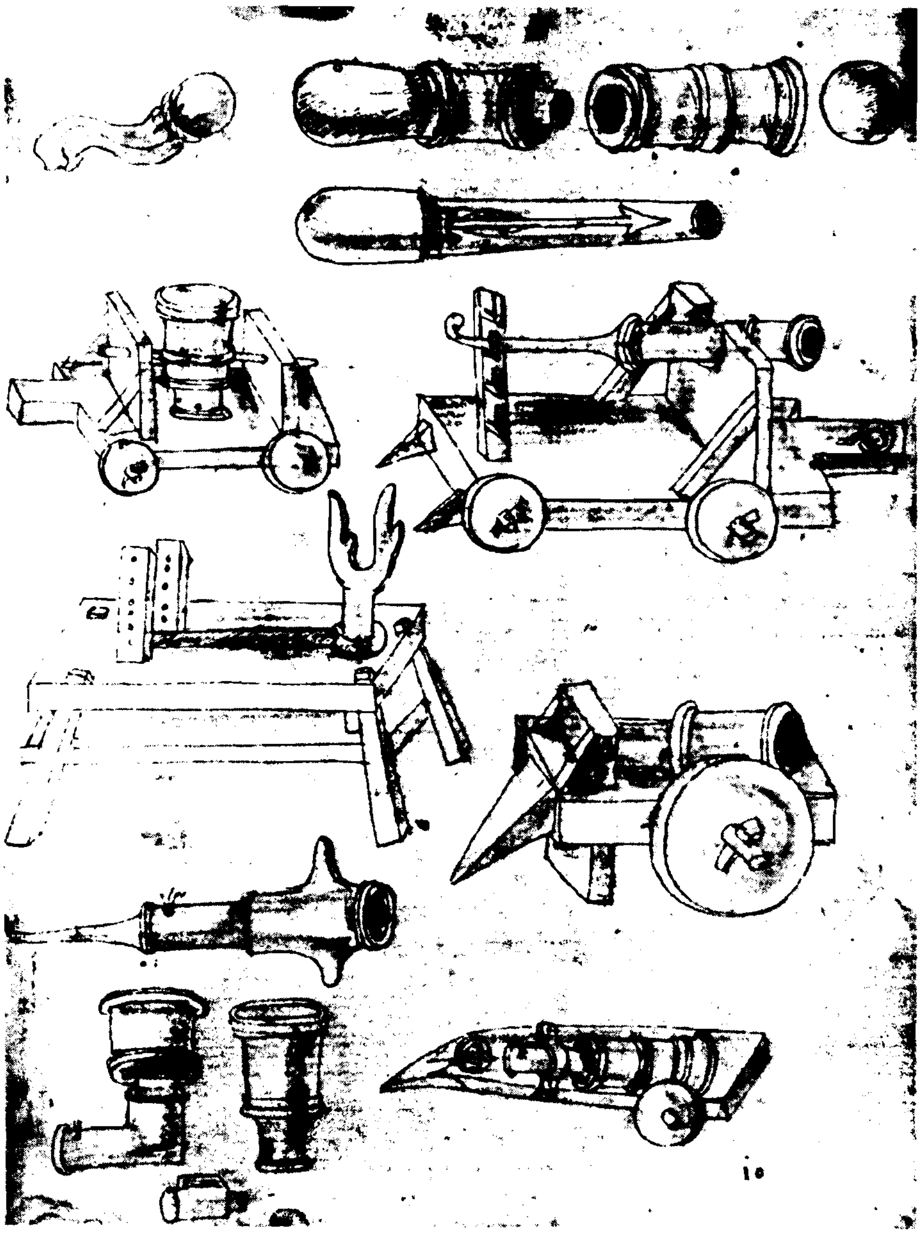
Renaissance artistic revolution in scientific drawing technique and in the designing of practical, workable machines. This contemporary artisan-engineer was Mariano di Jacopo called Taccola. He lived in Siena, officially as a notary, but his real passion was to become the "Sienese Archimedes" as he called himself. He managed to secure commissions working on the city's roads and water supply, and, in the 1430s, hoped to gain an even more prestigious appointment as engineer to the Holy Roman Emperor. This latter ambition might have been the occasion for his writings, for we now have a number of preparatory manuscripts for at least two treatises, one called *De ingeneis* and the other *De machinis*, "On Engines" and "On Machines."[10] The texts of these notebooks are in Latin accompanied by numerous little drawings. Taccola was certainly not a great artist, but he did have more talent than any of his artisan-engineer predecessors since Villard d'Honnecourt. He had been raised after all in Siena, a city second only to Florence as art center in the early Renaissance. He also knew Brunelleschi personally and recorded a conversation with the great man about the tribulations of the engineering profession.[11] Taccola, however, mentions nothing of Brunelleschi's perspective experiments, nor is there any evidence that he applied these theories directly in his drawings. Nonetheless, he was the first artisan-engineer to follow certain corollaries inherent in Brunelleschi's perspective system: namely, a more or less uniform viewing point for all objects in the same picture, and the drawing of size relationships in the picture which correspond to the real perspectival world.

A page from Taccola's *De ingeneis* shows a number of sketches of cannon types (see illustration). In the upper right corner, we may observe how this artisan-engineer tried to depict one cannon as if pulled apart with its powder chamber away from the barrel and the cannon ball suspended in front. Here is perhaps one of the earliest "exploded views" in the history of modern engineering. Oddly enough, the new Brunelleschian perspective system not only guaranteed geometric consistency in pictures, but it also granted the artist the right to suspend the laws of gravity in his pictorial world. Once perspective consistency is understood and the depicted objects perceived in their proper size, scaled according to distance, the viewer may imagine solid objects floating freely in space, such as the two halves of the cannon which he can then reconnect in his mind's eye because the nipple on one part and the hole in the other are proportioned to fit one into the other.

Of the two additional drawings from Taccola's notebooks shown here, the former shows a catapult for hurling fire bombs. The artist not only designed the complete machine but also added scale details of variations on the throwing mechanism. These are each identified by a letter and referred to in the text. What Taccola achieved in all these drawings were not new machines as such but new or improved conventions for *designing* machines, based on the new art-science of applied optics.

Perhaps his most far-reaching contribution to scientific drawing is seen in the "transparent view" of a suction pump. The viewer is asked to observe this device as if its encasing cylinder, here shown with a bit of shading to indicate



Page of Drawings from Taccola, *De ingeneis,* MS. Cod. Pal. 766, Biblioteca Nazionale, Florence, ca. 1433.

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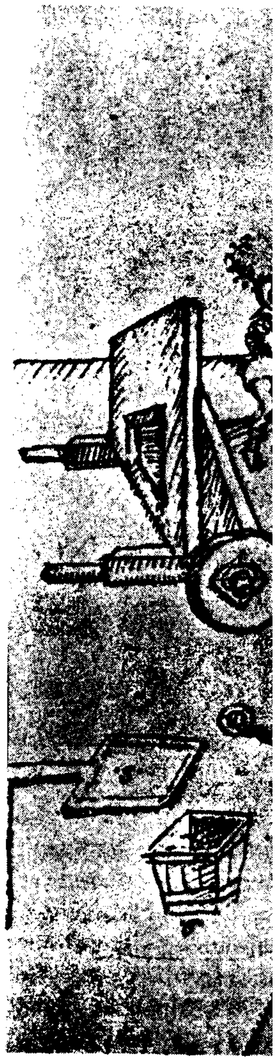

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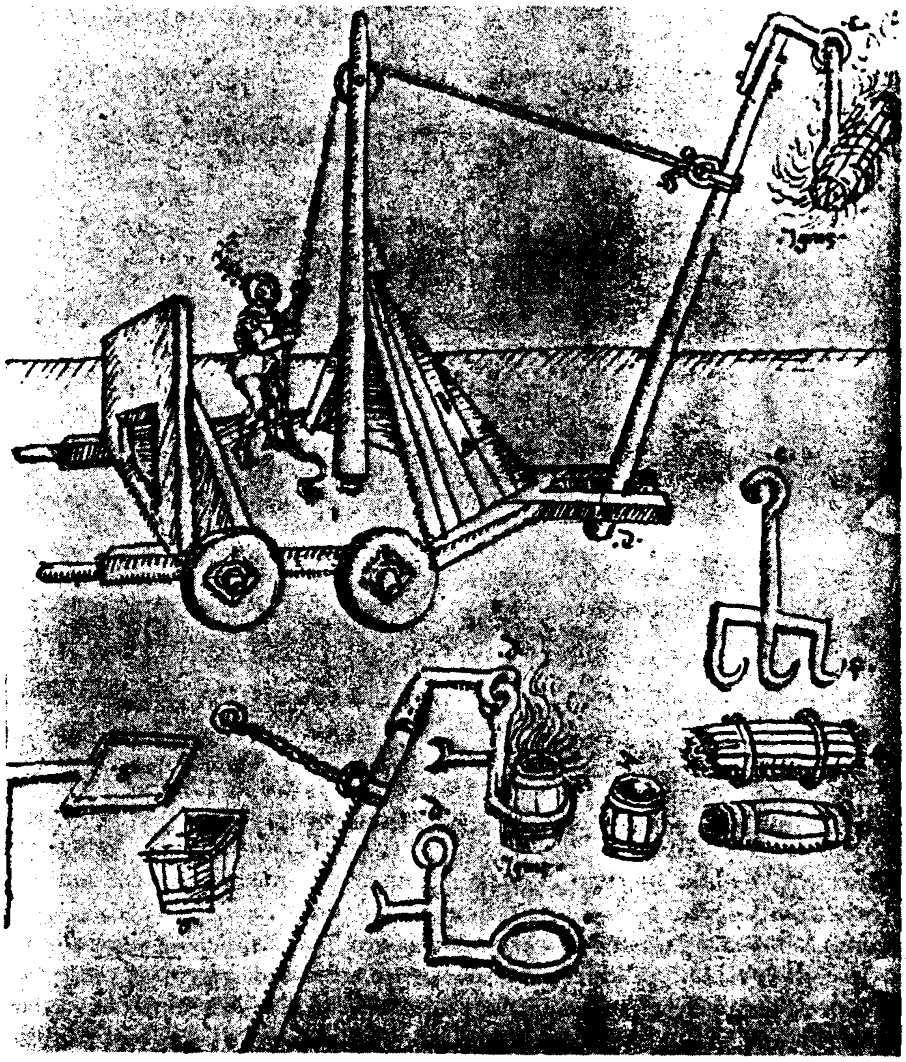
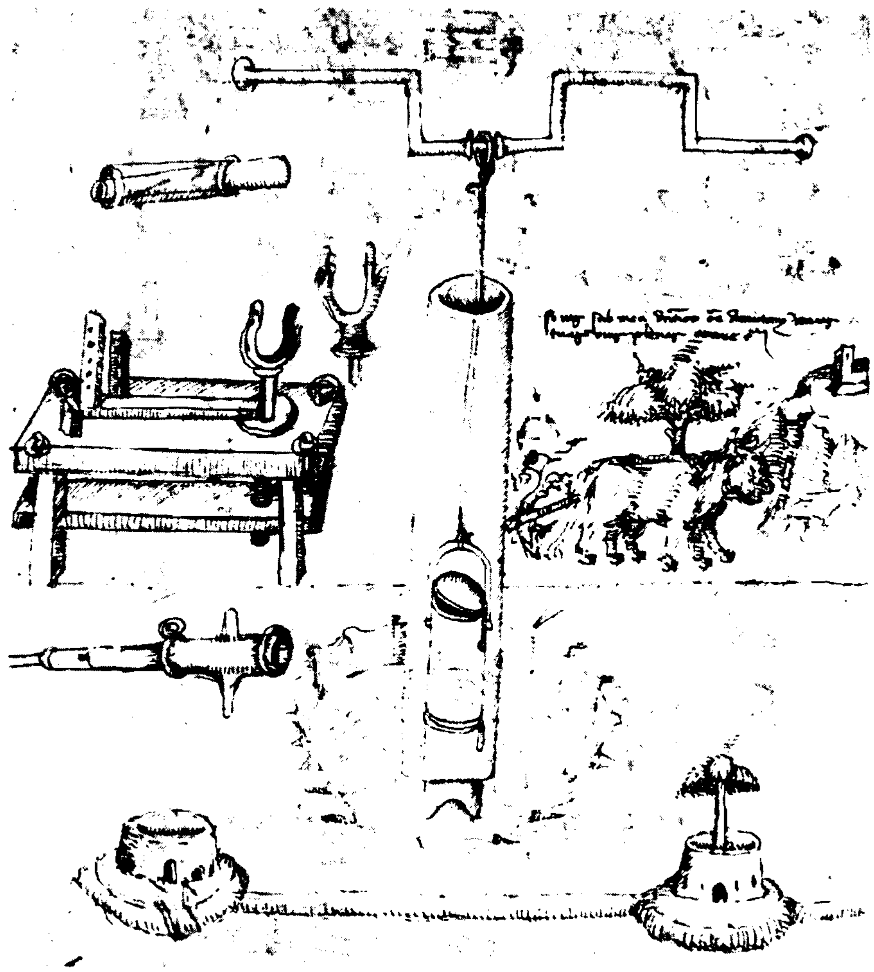
the convex outer surface, is transparent, exposing the piston and flap-valve mechanism inside. I would like to think that Taccola did not just invent this pump type, as one historian of technology has recently claimed,[12] but that he was the first to develop the perspectival "transparent view," and that only because of this latter contribution do we have first evidence of the machine. In other words, whether or not this suction pump was already known, Taccola's drawing now made it possible for anyone to understand the principle and to construct the pump without having to see first hand an actual working model.

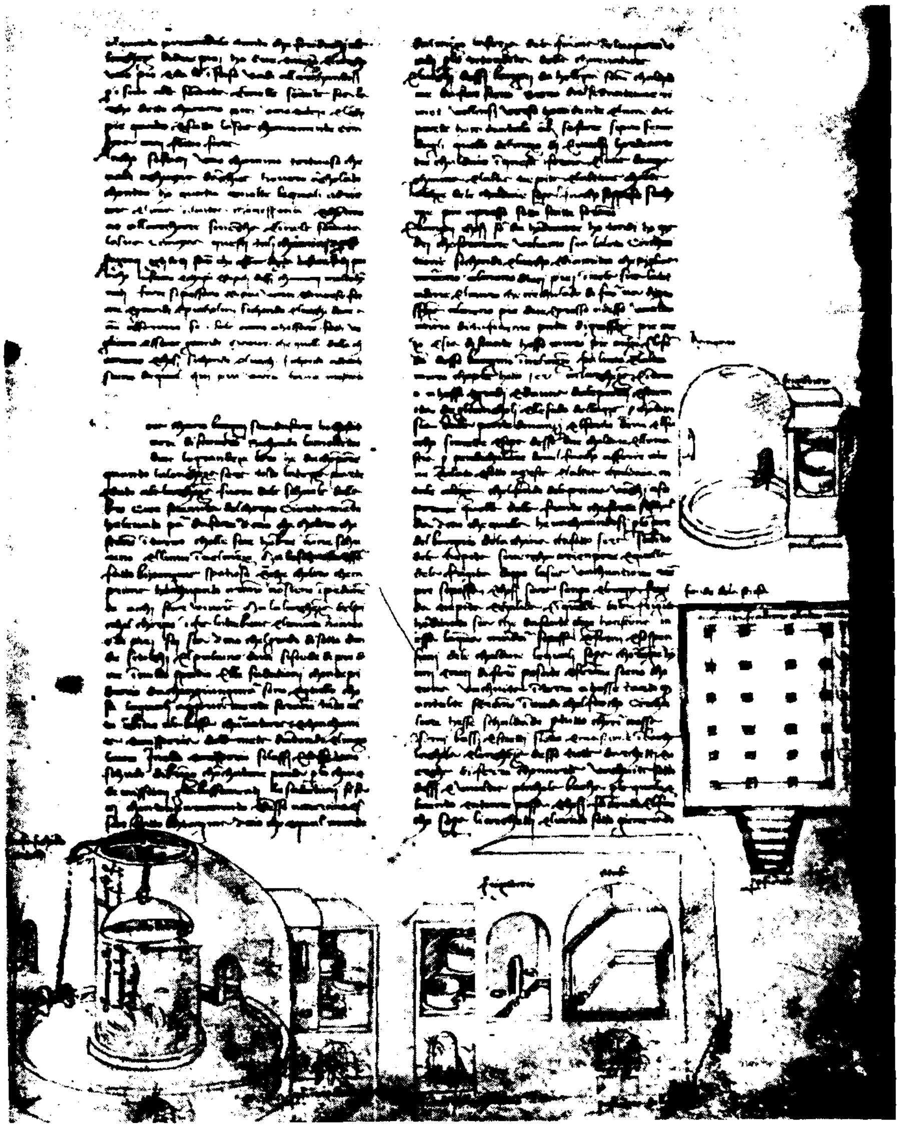


Page of Drawings from Taccola, *De machinis*, MS. Cod. Lat. 28800, Bayrische Staatsbibliothek, Munich.



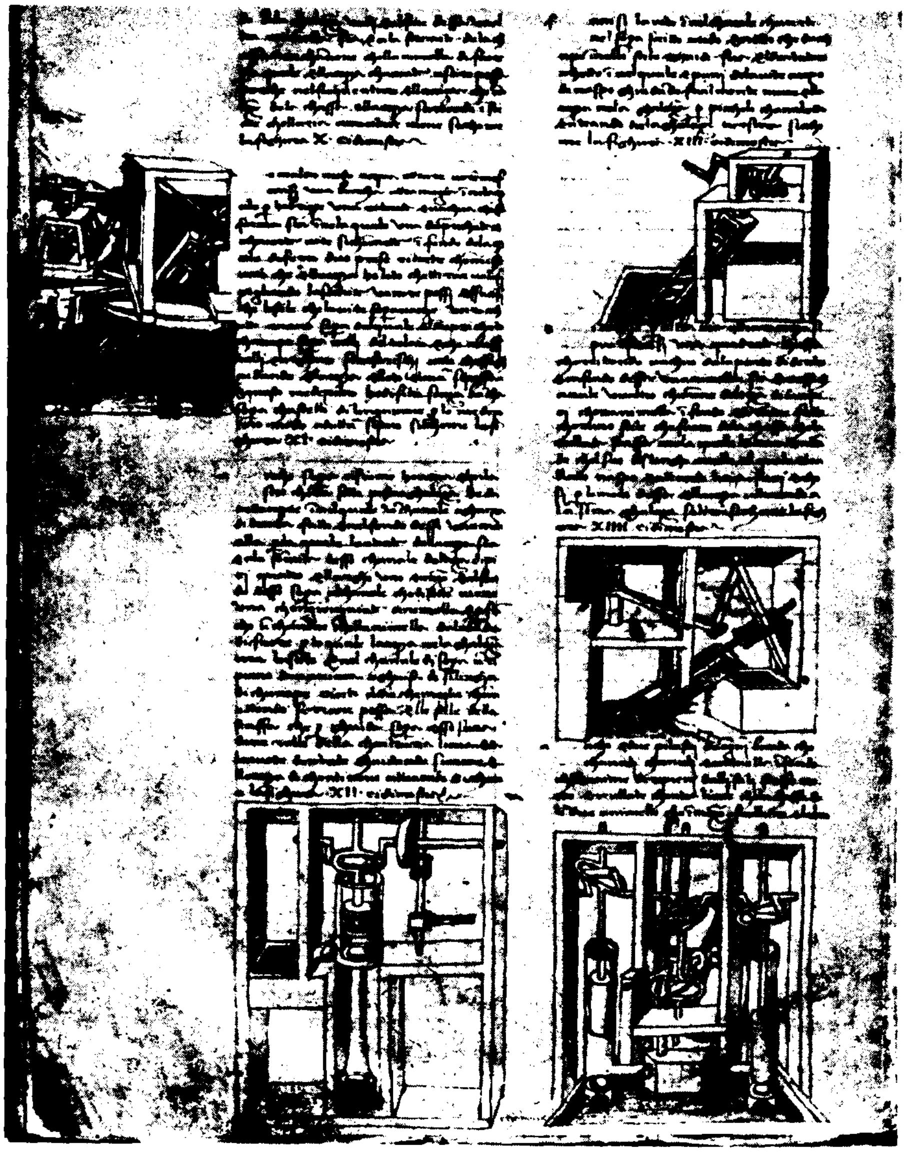
Page of Drawings from Taccola, *De ingeniis*, Cod. Lat. 197, Bayrische Staatsbibliothek, Munich.

Taccola's ideas and many of his original drawings passed into the hands of his fellow Sienese Francesco di Giorgio Martini during the second half of the fifteenth century. The latter had also read the recently available ten books on architecture by the ancient Roman Vitruvius. It therefore occurred to Francesco di Giorgio to write an even more ambitious treatise than Taccola's, covering not only military and civil engineering but containing designs for classical-style buildings.[13] He was also a better artist than Taccola; in fact, he was a practicing painter with a distinguished *oeuvre*, many examples of which are known and admired today. The manuscript pages shown here were written and illustrated by Francesco di Giorgio about 1475. The former is a description and reconstruction of a Roman bath. The artist neatly applied Taccola's "trans-



Page of Drawings from Francesco Di Giorgio Martini, *Trattato di architettura,* MS. Cod. Ashb. 361, Biblioteca Laurenziana, Florence.

parent view" technique to the exposition here of *tepidarium* and *frigidarium.* Perhaps Francesco di Giorgio's most ingenious application of the "transparent view" was to his own modification of Taccola's suction pump which we may observe in the second illustration of his pages, this one (from his *Trattato* manuscript now in the *Biblioteca Nazionale* in Florence) showing a number of water-raising devices. In fact, Francesco di Giorgio designed so many different



Page of Drawings from Francesco di Giorgio Martini, *Trattato di architettura*, ca. 1480. MS. Cod. Ashb. 361, Biblioteca Laurenziana, Florence.

water pumps that one can hardly believe that his drawings were merely copies of already existing, working models. It would seem, indeed, that these designs were either creations of his own imagination or modifications of drawings by others. This is to say that Francesco di Giorgio is one of the very first inventors in the history of technology who tested mechanical principles, designed appropriate machines, and worked out certain bugs apparent in the similar designs of his predecessors, almost entirely through the medium of drawing. Francesco di Giorgio's example may well have inspired Leonardo da Vinci, who owned and annotated one of the Sienese artisan-engineer's manuscripts.[14]

Let us analyze one such design in the *Trattato* example. In the lower right-hand corner of the illustration, we see Francesco di Giorgio's representation of a reciprocal suction pump after Taccola. In the original Taccola design (see illustration above), we note that the piston is attached to the crank by only a rope. This is because Taccola realized that the crank makes a rotary motion as it raises and lowers the piston, and this must naturally cause whatever connects the crank to the piston to oscillate. Since a rope is flexible, Taccola thought to use it instead of a more stable connecting rod which might unduly force the piston to bind against the cylinder sidewalls. Francesco di Giorgio, on the other hand, apparently felt that Taccola's pump was still inefficient so he compensated for the rotary motion of his crank by designing a solid connecting rod with a loop. A hollow roller was to be placed around the connecting arm of the crank which then slipped inside the loop. This would allow the connecting rod to move up and down without oscillation and without decreasing the pump's efficiency through unnecessary friction.

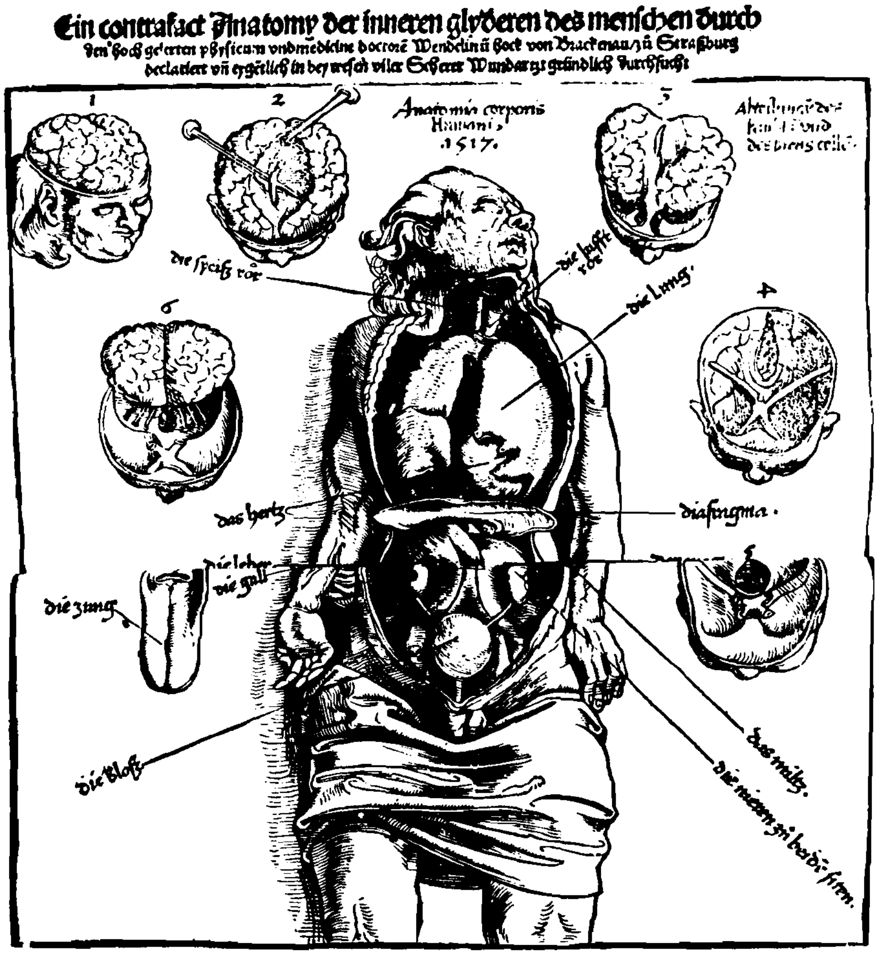
Francesco di Giorgio's machine-drawing conventions, derived and modified from Taccola, were much disseminated and copied during the late fifteenth and sixteenth centuries. Art historian Gustina Scaglia has examined dozens of manuscript notebooks from the period which attest to his widespread influence. Science historian Ladislao Reti has traced this influence on the printed "theater of machines" literature of the sixteenth, seventeenth, eighteenth, and even nineteenth centuries.[15] Since Leonardo da Vinci also had access to Francesco di Giorgio, it may well be true that his own scientific drawings, the most beautiful as well as informative pictorial documents on science ever seen up to the sixteenth century, owed to this revived artisan-engineer tradition which began in quattrocento Siena with Taccola. In a remarkable article on the fifteenth-century notion of "genius" and "invention," art historian Martin Kemp has shown that until the time of Leonardo, the word *ingegno* was rarely applied to makers of pictures. To earn that accolade, as did Brunelleschi in his epitaph, one had to be an architect or builder of actual machines. Toward the end of the century, however, the word *ingegno* begins to be associated with painters. This was clearly a tribute to their ability, as with Francesco di Giorgio and Leonardo, to draw pictures from which actual buildings and machines could then be constructed.[16]

Yet it is a sad fact that neither Leonardo's nor Francesco di Giorgio's manuscripts were ever set to type in the new printing press. Their revolutionary illustrations were never published over their own names until centuries later. Leonardo's drawings showed special ingenuity in the application of "exploded," "rotated," and "transparent" or "cutaway views," and he was also the first artisan-engineer to apply these postlinear perspective conventions to the representation of anatomical details. Leonardo himself was not resistant to printing; he even made a drawing of a printing press, but he did not trust the artisans of his day who cut other people's pictures into woodblocks or copper engravings. In the 1490s there were few *Formschneider* skilled enough to render the subtleties and nuances of Leonardo's art into an acceptable print.

Another force also intervened in late fifteenth-century Italy which helped delay the printing of Francesco di Giorgio's and Leonardo's notebooks. This was the publication of Roberto Valturio's *De re militari* in 1472, the first printed book on engineering to appear in Western Europe. It had been commissioned originally by Sigismondo Malatesta, Lord of Rimini, infamous *condottiere* and famous patron of classical learning. Valturio's book was not so much a practical treatise as a humanist tract on ancient Roman warfare. Valturio himself was a Latin scholar with little field experience in engineering. He seems also to have bade his illustrator not to draw diagrams as aids to construction but rather as deliberately archaized images fashioned to look like ancient cameo decorations. Nonetheless, so popular did his book become that other princes and classical buffs ordered their own hand-illuminated manuscripts copied from the printed edition.[17] The Duke of Urbino even had sculptural reliefs made from some of Valturio's prints which were then mounted on the facade of his palace.[18] Valturio's *De re militari* only added to the general European obsession for things antique during the late fifteenth and sixteenth centuries, and managed, unfortunately, to discourage at the same time the printing of more practical books on military and civil engineering.

Not until the second decade of the new century, really, did the printing industry turn out scientific books in which the illustrations approached the quality of Francesco di Giorgio's or Leonardo's drawings. This resurgence of interest was due in part to the tremendous technological advances in the printing trade itself, in the reproduction techniques of the woodblock and copper engraving. In any case, the scientific illustration conventions of "exploded," "rotated," and "transparent views," were then carried over into the print media, and suddenly, after about 1517, there began a flow of books on all manner of technical subjects, such as surgery, architecture, mining and metallurgy, anatomy, ballistics, machines for hauling and lifting, hydraulics, and even books on how to draw in linear perspective. These illustrated treatises all exhibit consistent, highly developed scientific pictures in which the conventions we have been speaking about were commonly used and assumed to be universally understandable by all readers.

In this paper I can do no more than present a random sampling. This page from a German language surgical text written by Laurentius Phryesen was published by Johannes Grüninger of Strasbourg in 1518. The illustration is by an artist named Hans Wechtlin, a follower of Dürer, who drew a male cadaver, obviously from "life," in a sophisticated "cutaway view." Moreover, the artist added "exploded views" of the head which had probably been dissected only after he had sketched the whole body. Wechtlin shows here a series of views of the brain being removed from the skull, step-by-step, with even the cranial nerves depicted in one remarkable detail.[19]



Hans Wechtlin, Woodcut print of an Anatomized Cadaver, from Laurentius Phryesen, *Spiegel der Artztney* Strasbourg, 1518. Francis A. Countway Library of Medicine, Harvard University, Boston, Mass.

Next pictured is a page from the 1556 Latin treatise *De re metallica* by Georg Bauer (Agricola). This large and learned volume on the mining and metallurgical industry is a recognized classic of the German wood-block artist's skill.[20] Here we see a beautifully composed picture of a double suction pump deployed in a mine shaft. The artist applied the "cutaway view" to the surface of the earth so that the insides of the mine are exposed like the viscera in Wechtlin's cadaver. He also showed the mechanism of the suction pump in a separate "transparent view" and again the disassembled parts of the pump "exploded" on the ground at lower right. These by now taken-for-granted conventions were similarly applied in all the illustrated, printed scientific literature of the later sixteenth century, especially in the wealth of anatomy books which fol-

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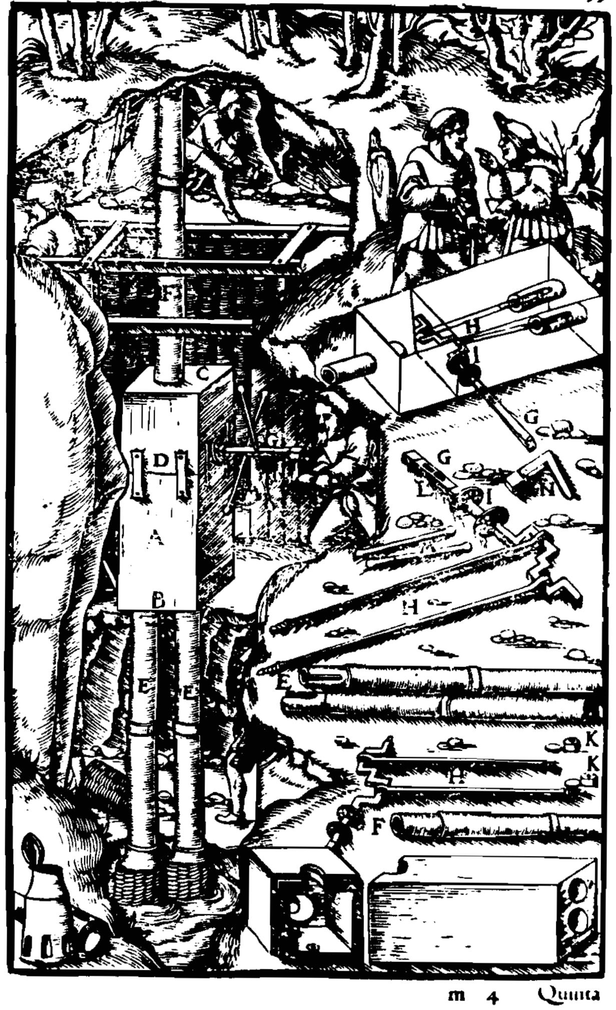

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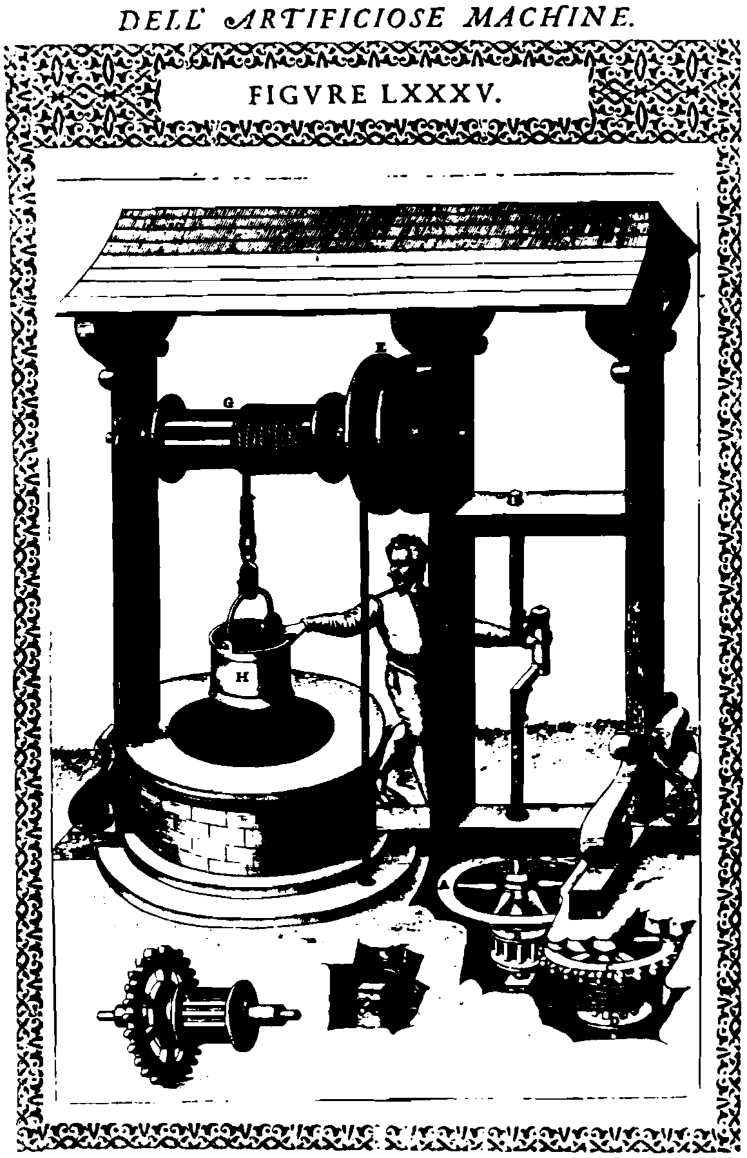
Woodcut print from Georg Bauer Agricola, *De re metallica*, Basel, 1556. Chapin Rare Book Library, Williams College, Williamstown, Mass.

lowed the lead of Andreas Vesalius's *De humani corporis fabrica* after 1543. Vesalius's illustrator, an artist very close to Titian if not Titian himself, established a mode of anatomical representation which has never been surpassed in either aesthetic or informational quality.

The example from yet another masterpiece of sixteenth-century scientific illustration, Agostino Ramelli's *Le diverse et artificiose machine* of 1588,[11] contains a copper engraving of a windlass for raising water from a well. The operator turns a vertical crank which then turns a lantern gear beneath the ground but exposed in a "cutaway view." This gear, lettered *B*, rotates another,



Engraving from Agostino Ramelli, *Le diverse et artificiose machine,* Paris, 1588. Houghton Library, Harvard University, Cambridge, Mass.

lettered C, which is attached to a reel around which is wound a rope. This rope can be followed, or better imagined, as running under the ground to where it reappears again in another adjacent "cutaway" opening. Then we see it around a pulley where it is directed above the ground and onto the windlass, *E*. At the lower left is another view of the same gear and reel, *C*, suspended so that we may examine it in more detail.

Jerome Wierx, *Nativity,* engraving from Jerome Nadal, *Evangelicae historicae imagines ex ordine Evangeliorum,* Antwerp, 1593. Chapin Rare Book Library, Williams College, Williamstown, Mass.

One especially interesting application of this new Renaissance didactic, scientific vocabulary is noteworthy because the scene shown here has nothing to do with science but with teaching the Roman Catholic religion. This engraving is one of 150 published in 1593 with a text by a Spanish Jesuit named Hieronymus Nadal. His publisher, the famous Christophe Plantin of Antwerp, commissioned these engravings for a book intended for use by Jesuit

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missionaries serving in China and Japan.[22] The purpose was to furnish the missionaries with field propaganda. The engravings were to be used as tools of the faith just as the machine and anatomical illustrations we have been examining were tools of science.

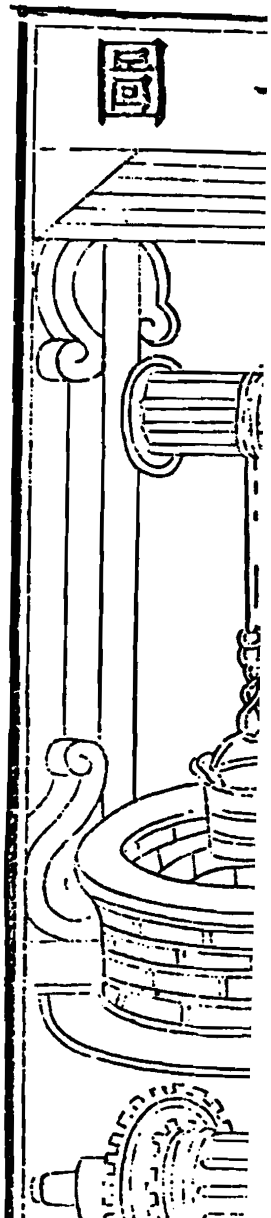
In the Christian religion, all Gospel stories are related and, of course, divinely foretold. The *Nativity of Jesus*, as depicted above, was announced to the shepherds by an angel and to the Magi by a star. Since early Christian times it had been commonplace in art to have these associated holy events all represented in a single picture even though they occurred at different places and times. This tradition continued even after the advent of linear perspective. Renaissance viewers became as accustomed as their medieval ancestors to suspend time unity in these religious pictures, just as they could suspend their sense of space unity in contemporaneous scientific illustrations. Religious art, like scientific art, shared a common didactic enterprise, and both came to rely on the same pictorial conventions. In the Nadal *Nativity*, we see, behind and to the right of the Holy Family in a cave manger, a little angel marked *K* hovering over the shepherds in the middle ground overlooking the city of Bethlehem, in whose open square we see the census takers, *B*. At the upper right, we note another little angel in the far distance, setting out the star, *M*. At the bottom right, there is a "cutaway view" in the ground beside the manger, exposing yet another little angel, *L*, this time announcing to Limbo the coming of the Savior. All these details and their accompanying letters are identified in alphabetical order in the text below the picture.

It is a relevant fact that not only was Nadal's book and all its engravings taken to China by the Jesuits but so also was Agostino Ramelli's. Furthermore, both of the illustrations we have just examined were copied by native Chinese artists during the early seventeenth century. One of the first acts of the Jesuit missionaries after they established themselves in Peking in 1601 was to found a library for the latest European books on religion and science, as tools for proselytizing among the Chinese.[23] The Europeans also encouraged their converts to translate and publish these books in the Chinese vernacular. These woodcut prints copied by Chinese artists after Nadal's *Nativity* and Ramelli's windlass pump respectively. The first appeared in a Chinese manual on the Rosary published about 1620. The second was included in a book entitled *Ji Qi Tu Shuo*, printed in 1627 by a Chinese convert named Wang Cheng. The latter was a scholar and admirer of the many European machine treatises like Ramelli's in the Jesuit Library. With the aid of Johannes Schreck, one of the most learned Jesuits of the period, Wang Cheng selected some fifty pictures from the various "theater of machines" books and had them copied and printed along with a digest of the texts. His title translated means "Diagrams and Explanations of Wonderful Machines (from the Far West)."[24]

One immediately notices in these printed copies how completely the Chinese artists "orientalized" the scenes, substituting not only Chinese physiognomical types for the principal figures but also Chinese parallel for Renaissance converging perspective. Chinese artists were also unfamiliar with chiaroscuro, the

Woodcut of the Nativity from a Chinese edition of João da Rocha, *Metodo de Rosario*, Lisbon, 1619/20. Institutum Historicum S.I., Rome.

rendering of uniform light and shade. Thus, both prints here illustrated have none of the relief quality which always distinguishes European art of the Renaissance. In the Chinese *Nativity* copy, the artist not only failed to appreciate the dramatic lighting effect of the manger cave with the Christ Child as symbolic source of illumination, but he also misunderstood the meaning of the darkened convex exterior of the cave underneath the wooden shed roof. He apparently thought the dark cross-hatching of the engraver's burin indicated some sort of reed matting, such as one frequently finds in the Orient. Thus he misconstrued the cave altogether, rendering its mysterious darks as so many



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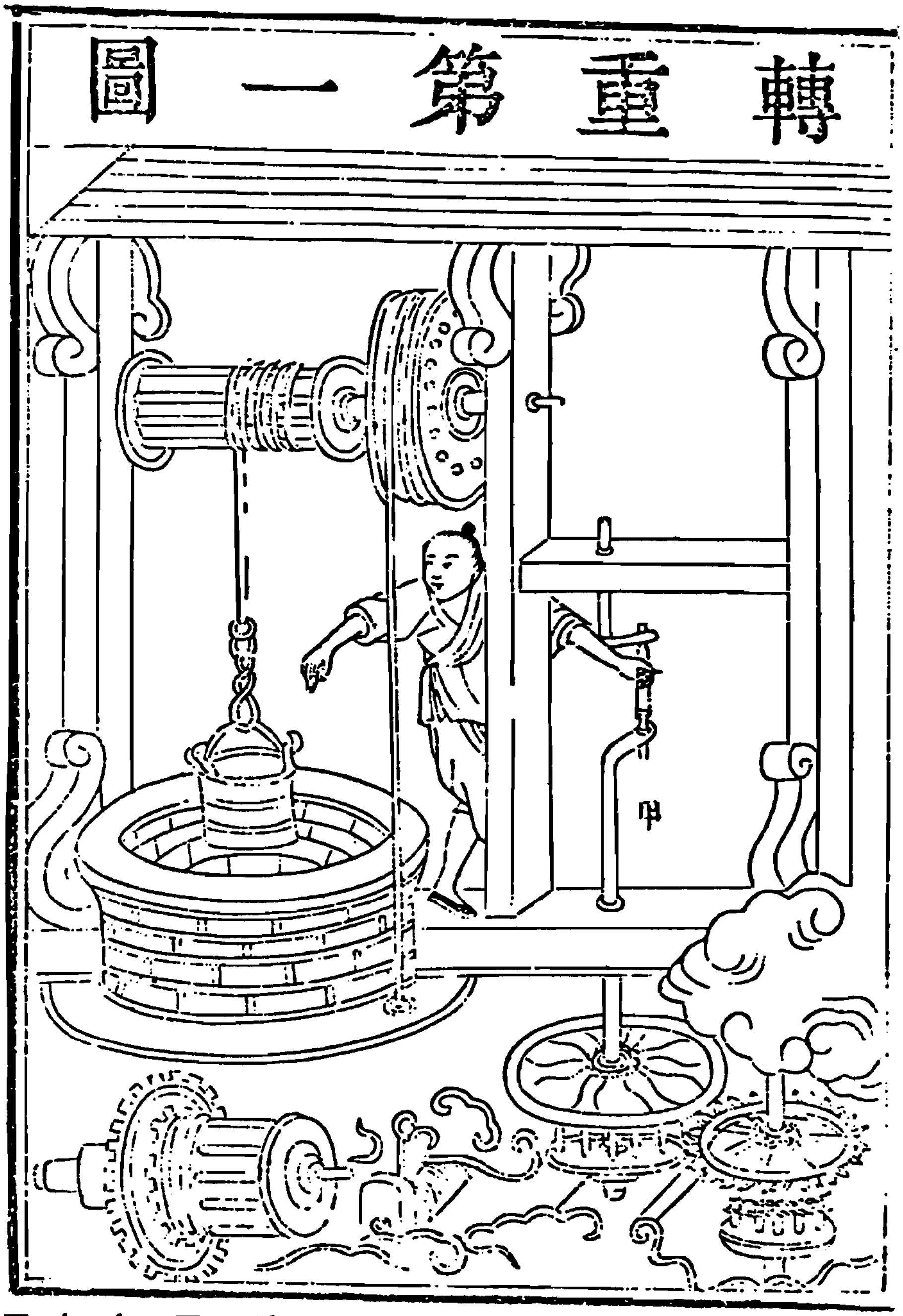


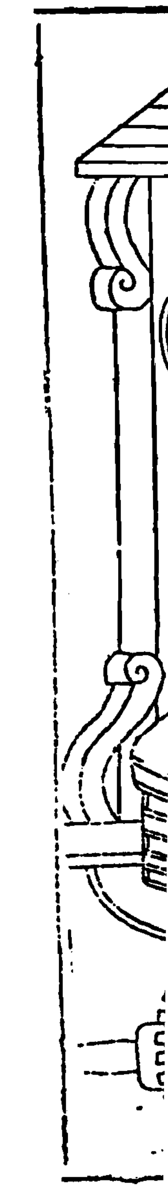
Woodcut from Wang Cheng, *Ji Qi Tu Shuo*, Peking, 1627. Harvard Yen Ching Library, Cambridge, Mass.

mats nailed to the cross beam below the roof, forming a flat, irregular opening into an ordinary shed. One observes also that the Chinese copyist left out all the little typological details, because he apparently did not understand the convention. In the heavenly aureole about the *Nativity,* for instance, he omitted the angels carrying the lettered banderole.[25]

Let us follow how the Chinese copyist interpreted Ramelli's machine. We shall make no aesthetic judgment and ask only whether or not the picture communicates information about how the well works; whether or not any viewer, Chinese or European, could make use of this illustration—as we assume he could Ramelli's original—to build from it a working model. Our first observation confirms that the Chinese artist, who was unfamiliar with the "cutaway view," was especially confused about the machinery which Ramelli showed beneath the ground. Indeed, since he had no parallel convention in his own style, he substituted for the unclear (to him) edges of the cutaway hole in the ground, a number of squiggly shapes which Chinese artists often used to denote apparitions or miraculous events. In the meantime, the artist did not concern himself with the all-important rope, which ran from the gear-driven reel, passed under the ground, and ran up again to the windlass. The artist did show a bit of this cord just below the well, but its crucial connection to the winding reel was ignored. Also, since he had no similar convention for the "exploded view," the Chinese illustrator copied Ramelli's detail of the reel and gear at the lower left with no understanding that it was the same component working together with the other parts of the apparatus at lower right.

Is it possible that the Chinese artist possessed his own special conventions, which his own audience understood, for communicating information about such a machine? This seems doubtful, especially if we examine another Chinese copy of Ramelli's device published in 1726, in *Tu Shu Ji Cheng,* the great encyclopedia of the Qing Dynasty. This print was not made directly from Ramelli's but was copied from the *Ji Qi Tu Shuo.* Here we see clearly that the second Chinese artist not only reproduced the same errors but even misunderstood the earlier copyist's Chinese conventions. The later artist was unsure of what the little squiggles represented, which the *Ji Qi Tu Shuo* illustrator substituted for the "cutaway view." Instead of an apparition, the second artist thought these wavy lines stood for water, so he translated them into another convention, the common Chinese representation for billowing surf.

What are we to make of these strange incongruities in Chinese so-called scientific illustration? It must be understood that the *Ji Qi Tu Shuo* (the rest of its fifty-odd plates have all similar if not even more egregious misinterpretations) is not an isolated case. It can not be dismissed on the grounds that a more talented Chinese artist could have made truly intelligible copies. Not only do all Chinese pictures of technical subjects, in the hundreds of books published in China from the ninth to the nineteenth century, lack systematic chiaroscuro and linear perspective, but they are just as consistently impressionistic. They only suggest the forms and functions of the things represented and never show accurate dimensions or proportions to scale. This is true even in Chinese



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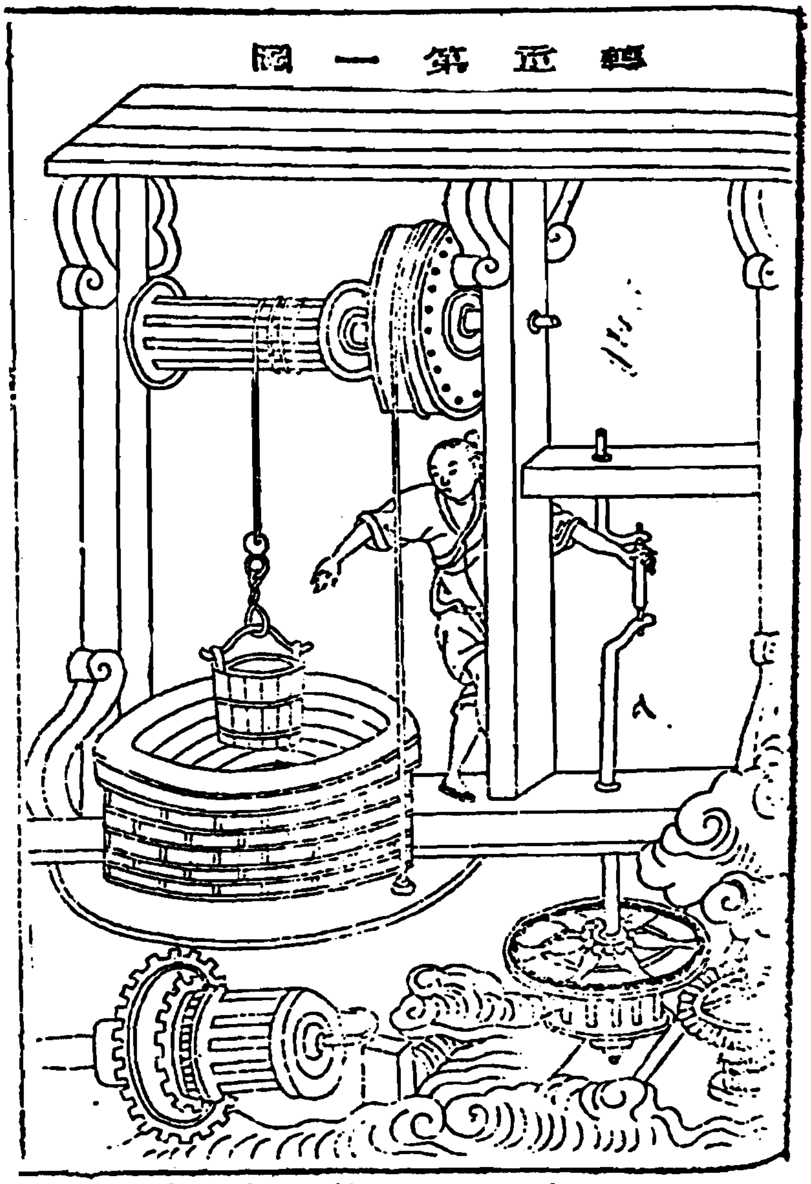

Woodcut from *Tu Shu Ji Cheng*, Peking, 1726. Harvard Yen Ching Library, Cambridge, Mass.

pictures of indigenous technical and scientific subject matter. The Chinese illustrator was expected to be decorative, not didactic in his representations of the objects described in the verbal texts.[26]

One might wonder what Wang Cheng himself thought when he first examined the "page proofs" of the illustrations for his book. Like the mandarin he was, this author seems not to have considered the artist as his intellectual and social equal. At least he did not share with him his own knowledge of how the Western machines were supposed to work. Indeed, members of the Chinese mandarin class generally considered the mechanical arts to be socially demeaning. They enjoyed the results of a clever water pump, but the matter of its building should be left to laborers who would not be expected to appreciate pictures. In Europe, on the other hand, quite a different attitude was shared by many aristocrats such as Galileo's own patron, the Grand Duke Ferdinand II of Tuscany, Francis Bacon in England, and Thomas Jefferson in America, that knowledge of technical matters was an upper-class social duty. In fact, the deluxe illustrated books we have been examining, such as Ramelli's, could be afforded only by the rich. I propose that this developing European attitude of sympathy for science and the mechanical arts was both incited and encouraged by the illustrations in these sixteenth-century printed books. In China, as we have noted, the visual arts offered no encouragement to technology and science at all. Never, as far as I know, do we have a case where a Chinese designed a machine solely by means of pictures as did Taccola, Francesco di Giorgio Martini, Leonardo, and Ramelli, or used pictures to solve problems of anatomy as did Vesalius. Separate geniuses of art and science the Chinese had aplenty, but never in China was genius for both art and science combined in one person like Francesco di Giorgio or Leonardo.

The relative states of the arts and the sciences in the oriental civilizations during the sixteenth and seventeenth centuries offers a veritable laboratory for studying and isolating factors which promote or impede scientific and technological growth in any society. What happened or did not happen in these oriental civilizations while the Jesuits were bombarding them with foreign ideas may reveal insights even of the origins of our own Western scientific revolution. Art historians, science historians, and even perceptual psychologists with fluency in the Eastern languages should devote research to the school textbooks in China, Japan, and the progressive Islamic countries from the seventeenth through this century, to discover just when, and how much, Western-style illustrations replaced the native in these books. My hunch is that such research will reveal some ratio between the influx of Western pictorial forms and the rate of expanding industrialization and adaptation to modern science in the Eastern nations. If this could be proven, then, indeed, we might infer a similar relationship also existed in Renaissance Europe. At least we should have a *prima facie* case that Galileo could not have done what he did in Ming Dynasty China. He needed precisely the kind of visual education, the familiarity with Renaissance-style pictures in contemporaneous textbooks, only available in the school rooms of sixteenth-century western Europe.

When the documents are finally in, and the so-called Third World has reached full scientific and technological parity with the West, it may well be understood that one of the fundamental problems revolutionary peoples had to solve, transcending the polarized politics of capitalism and communism, was the psychological adjustment to the peculiar visual conception of the natural world first set forth by the artists of the European Renaissance.

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3. See also Erwin

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5. Marshall Clage
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6. See H. R. Ha
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7. See A. R. Ha
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8. See E. Wicker
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9. See, for instan
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*This paper, while containing many of the same examples and arriving at the same conclusion, is an extension of that given before the Folger Symposium in 1978. The original lecture, entitled "The Renaissance Artist as Quantifier," was published in Margaret Hagen, ed., *The Perception of Pictures* (New York, 1980), 1:179–213. I am especially indebted for many of my thoughts and inspirations in both essays to James S. Ackerman, Creighton E. Gilbert, Thomas B. Settle, Cyril Stanley Smith, and Nathan Sivin. My sincere thanks also to Father Charles O'Neill, S. J., for his hospitality and generosity in allowing me to consult the holdings of the Institutum Historicum S.I. in Rome.

1. Two recent papers by historians of science are refreshing exceptions to my generalization; see Eugene S. Ferguson, "The Mind's Eye: Non-Verbal Thought in Technology," *Science* 197 (1977): 827–36, and Bert S. Hall, "Technical Treatises 1400–1600: Implications of Early Non-Verbal Thought for Technologists" (Unpublished lecture read before the meeting of the Society for the History of Technology, Washington, D.C., 22 October 1977). Two other useful if conventional surveys of scientific illustration are Alois Nedoluha, "Kultur-geschichte des technischen Zeichnens," *Blätter für Technikgeschichte*, 19 (1957), 20 (1958), and 21 (1959); and F. M. Feldhaus, *Geschichte des technischen Zeichnens* (Wilhelmshafen, 1959). The history of medical illustration, while considerably more studied than that of technical drawing, seems to be pursued in complete ignorance of the latter. For instance, many of the conventions invented by early Renaissance engineers for making clear their drawings of machines, such as the "exploded" and "cutaway views," only later applied to anatomical diagrams, are treated in the current medical history literature as the singular achievement of anatomical illustrators, Leonardo in particular (see especially, O. Benesch, "Leonardo da Vinci and the beginning of Scientific Drawing," *American Scientist 31 (1943): 311ff., and Robert Herrlinger, History of Medical Illustration from Antiquity to 1600* (New York, 1970; translated from the German edition, Munich, 1967). I am currently working on a book about art and science in which one of the major themes is the relationship between Renaissance machine drawing and anatomical illustration, particularly the influence of the former on the woodcuts of Andreas Vesalius in his *De humani corporis fabrica* of 1543.

2. A rare exception, as always, is Erwin Panofsky; see his "Artist, Scientist, Genius; Notes on the Renaissance 'Dämmerung'," in W. Ferguson et al., *The Italian Renaissance, Six Essays* (New York, 1962), 121–82.

3. See also Erwin Panofsky, *Early Netherlandish Painting* (Cambridge, Mass., 1959), 1:1–51. pictures as Window

4. See especially Bertrand Gille, *Engineers of the Renaissance* (Cambridge, Mass., 1970; translated from the French edition, Paris, 1964); and Lynn White, Jr., "The Flavor of Early Renaissance Technology," in B. S. Levy, ed., *Developments in the Early Renaissance* (Albany, N.Y., 1972), 36–58. See also the useful older studies on the profession of artisan-engineer in the Renaissance: Carlo Promis, *Biografie di ingegnieri militari italiani dal secolo xiv* alla *metà xviii* (Turin, 1874), originally published under the title, *Dell'arte dell'ingegnere e dell'artigliere in Italia* . . . (Turin, 1841); T. Beck, *Beiträge zur Geschichte des Maschinenbaues* (Berlin, 1900); Alexander Keller, *A Theater of Machines* (New York, 1965); and William Barclay Parsons, *Engineers and Engineering in the Renaissance* (Cambridge, Mass., 1976; originally published in 1939).

5. Marshall Clagett, *Archimedes in the Middle Ages*, 3 vols. to date (Philadelphia, 1964+); see also A. G. Drachmann, *The Mechanical Technology of Greek and Roman Antiquity* (Copenhagen, 1963).

6. See H. R. Hahnloser, ed., *Villard de Honnecourt, kritische Gesamtausgabe des Bauhüttenbuches* (Leipzig, 1935).

7. See A. R. Hall, "Guido's *Texaurus*, 1335," in B. S. Hall and D. C. West, eds., *On Pre-Modern Technology and Science: A Volume of Studies in Honor of Lynn White, Jr.* (Malibu, Calif., 1976).

8. See E. Wickersheimer, ed., "L'*Anatomie* de Guido da Vigevano médicin de la reine Jeanne de Bourgogne (1345)," *Archiv für Geschichte der Medizin* 7 (1913): 1–25.

9. See, for instance, Jan B. Deregowski, "Pictorial Perception and Culture," *Scientific American* 227, no. 5 (1972): 82–90.

10. Taccola's manuscripts have been edited and published by James H. Beck, ed., *Liber tertius*

ingeneis ac edifitiis non usitatis di Mariano di Jacopo detto il Taccola (Milan, 1969); Gustina Scaglia, ed., *Mariano Taccola de machinis; the Engineering Treatise of 1449; Introduction, Latin Texts, Description of Engines and Technical Commentaries* (Wiesbaden, 1971); and G. Scaglia and Frank D. Prager, eds., *Mariano Taccola and his Book De Ingeneis* (Cambridge, Mass., 1972).

11. See F. D. Prager, "A Manuscript of Taccola, Quoting Brunelleschi on Problems of Builders and Inventors," *Proceedings of the American Philosophical Society* 92 (1968): 131–50.

12. Sheldon Shapiro, "The Origin of the Suction Pump," *Technology and Culture* 5 (1965): 571–80.

13. Francesco di Giorgio Martini's major manuscripts have been published in facsimile by Carrado Maltese and Livia Maltese Degrassi, eds., *Francesco di Giorgio Martini Trattati di architettura ingegnaria e arte militare*, 2 vols. (Milan, 1967). See also F. Paolo Fiore, *Città e Macchine dell'400, nei disegni di Francesco di Giorgio Martini* (Florence, 1978).

14. Now the Codex Ashburneanus 361, Biblioteca Laurenziana, Florence, Italy.

15. Ladislao Reti, "Francesco di Giorgio Martini's Treatise on Engineering and its Plagiarists," *Technology and Culture* 4 (1965): 287–98.

16. Martin Kemp, "The Quattrocento Vocabulary of Creation, Inspiration, and Genius in the Visual Arts," *Viator* 8 (1977): 347–99.

17. See Erla Rodakiewicz, "The *Editio Princeps* of Valturio's *De re militari* in relation to the Dresden and Munich mss," *Maso Finiguerra* 5 (1940): 15–82.

18. Giorgio Vasari originally claimed these reliefs for Francesco di Giorgio, but more recent scholars have acknowledged that at least some of the subjects were copied from Valturio by Ambrogio Barocci, father of the famous painter Federigo. See Pasquale Rotondi, Michele Provinciali, and Mauro Masera, *Francesco di Giorgio nel Palazzo Ducale di Urbino* (Novilara, 1970).

19. Phryesen's book, *Spiegel der Artztny,* and its illustrations by Wechtlin are discussed by Ludwig Choulant, *History and Bibliography of Anatomic Illustration*, ed. and trans. Mortimer Frank (Chicago, 1920; original German edition, Leipzig, 1852), 130–35.

20. Agricola's book has been republished in facsimile with English translation and notes by Herbert Clark Hoover and Lou Henry Hoover, London, 1912 (and reissued by the Dover Press, New York, 1950).

21. Ramelli's book has been reprinted in facsimile with extensive notes and English translation substituted for the original Italian and French by Eugene S. Ferguson and Martha Teach Gnudi, eds.,*The Various and Ingenious Machines of Captain Agostino Ramelli* (Baltimore, 1976).

22. Nadal's book, published thirteen years after his death, was one of the most ambitious undertakings of the famed Christophe Plantin press in Antwerp. Plantin himself spent years of time and trouble on it, seeking out artists to do the engravings and sponsors to put up the money. He, too, died before the book's completion, and it finally went to press under his successor Martinus Nutius, in 1593, entitled: *Evangelicae historiae imagines ex ordine Evangeliorum, quae toto anno in Missae Sacrificio recitantur, in ordinem temporis vitae Christi digestae*, See Josef Jennes, *Invloed der Vlasmsche Prentkunst in Indiä, China, en Japan, tijdens de XVIe en XVIIe eeuwe* (Louvain, 1943). For more recent art historical scholarship on Nadal's book, see Thomas Buser, "Jerome Nadal and Early Jesuit Art in Rome," *The Art Bulletin* 57 (1976): 424–33, and Lief Holm Monssen, "*Rex Gloriose Martyrum;* A Contribution to Jesuit Iconography, *The Art Bulletin* 63 (1981): 130–38.

23. This collection was known as the *Bei tang* Library, named for the "North Church," one of the four Jesuit missions established in Peking after 1601. A catalog of the original collection has been published by H. Verhaeren, *Catalogue of the Pei-t'ang Library*, 3 vols. (Peking, 1944–48). The author also published a more accessible preview of the above in *Monumenta Serica* (1939), 4.2, 605–26.

24. See Fritz Jäger, "Das Buch von den wunderbaren Maschinen; Ein Kapitel aus der Geschichte der abendländisch-chinesischen Kulturbeziehungen," *Asia Major*, n.s., 1, nr. 1 (1944): 78–96; also Joseph Needham, *Science and Civilisation in China* (Cambridge, 1954), vol. 4.2, 211–18. I am grateful to Mr. Chin-shing Huang of Harvard University for his help in the translating of the *Ji Qi Tu Shuo*.

25. This Chinese copy and fourteen other prints after Nadal's *Imagines* were published in China

to illustrate Father Joao da Rocha's *Metodo de Rosario* of 1619/20. It has been reproduced along with the entire series and their original prototypes in Pasquale D'Elia, S.J., *Le origine dell'arte cristiana cinese, 1583–1640* (Rome, 1939), 67ff.; see also John E. McCall, "Early Jesuit Art in the Far East; part IV: In China and Macao before 1635," *Artibus Asiae* 11 (1948): 57–58.

26. A good survey of the Chinese printing industry during the Ming Dynasty is given by K. T. Wu, "Ming Printing and Printers," *Harvard Journal of Asiatic Studies* 7 (1942/43): 203–60. The author tends to blame any deficiencies in printed pictures and books at this time on the decadence of the Ming period in general.