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The Unseen World

Printing

Reading a book is an individual activity done quietly and on one's own. We take this act so for granted that it is hard to imagine that the familiar object in our hands was once such a shocking innovation that it not only made the communication of ideas and knowledge possible but also replaced the custom of reading unpunctuated texts aloud in a group (McLuhan, 1964). The printing press, gunpowder, and the compass are three mechanical inventions that are often grouped together. In *The City of the Sun* (1602), Campanella vividly describes them as a series of conquests that went hand-in-hand with the acceleration of history itself: "there has been more history in 100 years than in all the world in 4,000; and more books have been written in these 100 years than in 5,000; and the magnet, printing, and guns are great signs of world unity" (Campanella, 1941: 100). In 1620, Francis Bacon wrote that their effect was one of such radical change "that no empire, sect, or star seems to have exerted greater power in human affairs than these mechanical inventions" (Bacon, 1975: 635–6).

This was no overstatement. The fusion of different processes (the manufacture of paper and ink, the development of moveable and metal type, and printing itself) into a completely new technology introduced to Europe – 300 years early – the "theory of interchangeable parts" that lay at the heart of modern manufacturing technology (Steinberg, 1955). Johannes Gutenberg began printing books in Mainz (his Bible dates from 1456) using a technique that was perfected in the sixteenth century, remained unchanged until the nineteenth, and is even still used today. In 1480, there were active printing presses in more than 110 cities in Europe: 50 were in Italy, 30 in Germany, 8 each in Holland and Spain, 5 in

Belgium and Switzerland, 4 in England, 2 in Bohemia, and 1 in Poland. By 1500, only twenty years later, 286 cities boasted presses. L. Febvre and H. J. Martin have calculated that by 1500, 35,000 editions of 10,000–15,000 different works had been printed, and at least 20 million books were in circulation. Over the course of the seventeenth century there were 200 million copies in circulation (Febvre and Martin, 1958: 396–7).

The small-format books published by Aldo Manuzio have been compared to today's paperbacks. Along with Paris and Lyon, Venice became a major publishing center. At the end of the sixteenth century, the first international book fairs were held in Lyon, Medina del Campo, Leipzig, and Frankfurt. The number of copies per edition could vary from 300 to 3,000 but the average was 1,000.

The spread of ideas and the advancement of learning now required large capital investments and considerable risk-taking for the entrepreneur. These certainly had not been typical problems associated with scholarship for either the monk or the humanist.

Ancient Books

The great Italian humanists (Leonardo Bruni, Guarino Veronese, Giannozzo Manetti, and Lorenzo Valla, to name a few) believed that studying the great classics of the ancient world signified a return to a civilization superior to theirs, and the unattainable model for all forms of human society. Yet the humanists were not simply passive imitators, and their writings revealed a constant debate about the "barbarity" of medieval Scholasticism and the dangers of classicism itself. The need for *aemulatio* rather than *imitatio* became the battle cry of European intellectuals from Angelo Poliziano to Erasmus of Rotterdam. The lost texts that were rediscovered and commented on by humanists were anything but simple documents. The ancient texts upon which they exercised their refined philology contained – in their eyes – knowledge that was immediately useful to science and its practice. Access to books published in the original Greek, and to translations no longer based on medieval Arabic translations of Greek originals, had a significant effect on the development of scientific knowledge. Important editions included Euclid in the original (Basel 1533) and its Latin translation by Federico Commandino (Pesaro, 1572); Archimedes in Greek (Basel 1544) and Commandino's Latin translation of it (Venice 1558); as well as, once again, Commandino's translations of the *Conics* by Apollonius and the mathematical collections of Pappus (Bologna 1566; Pesaro 1588); Ptolemy's *Almagest* (Basel 1538) and translations of his *Geography* (virtually unknown until the Middle Ages). The first Latin translation of Hippocrates (Rome 1525) was quickly followed by its publication in the original Greek in 1526 (Venice) and 1538 (Basel). Galen's vast opus (much of which had been translated in the Middle Ages from Arabic and contained many spurious inscriptions) was carefully organized and integrated after the discovery of treatises previously unknown in the Western world. Galen's work appeared first in Latin in 1490 (Venice) and in Greek in 1525 (Venice), and was followed by the edition edited by Joachim Camerarius and Leonhart Fuchs (Basel 1538).

The Old and the New

The relationship between two characteristics of the Renaissance – the *rediscovery of the ancients* and *the sense of the new* – were related in a complex way because the leaders of the Scientific Revolution regarded antiquity with a completely different attitude than had the humanists. Bacon and Descartes used classical texts while at the same time rejecting the exemplary nature of the classical world. They rejected not only pedantic imitation and passive repetition but also *aemulatio*, still considered essential by humanists but not so by these new thinkers. Indeed even the humanist contextual basis for comparison with the ancients was rejected: Descartes pointed out that when one spends too much time traveling one becomes a foreigner at home, much in the way that one who is too curious about the past becomes ignorant of the present. Bacon felt that the spirit of the ancient Greeks was narrow and limited, and if their path were followed it would be impossible to imitate them. It was necessary to change course and take on the role of "not of judges but of guides" (Bacon, 1887–92: III, 572).

In 1647, Blaise Pascal still believed that it was not possible to propose new ideas with impunity because respect for antiquity "had reached such a level that all its thoughts are taken as oracles and all that is unintelligible is considered a mystery" (Pascal, 1959: 3). Yet even *aemulatio* no longer made sense. The ancients explained the Milky Way in the only way they could given their limited resource: the naked eye. The fact that we know more about nature today than they did allows us to hold new opinions without offending them or seeming ungrateful. For this reason, and without contradicting them, we may say the opposite of what they said (ibid.: 7–8, 9–11).

Because the new astronomy not only pushed the outer reaches of the universe immeasurably but in some cases even proclaimed it was infinite, it gave many the distinct impression that traditional knowledge as they knew it had come to an end. In 1657 Pierre Borel wrote that "we know nothing that is not or cannot be debated." Astronomy, physics, and medicine "vacillate every day and see their very foundations crumble." Petrus Ramus had destroyed Aristotle's philosophy, Copernicus Ptolemy's astronomy, Paracelsus Galenic medicine: "we are compelled to admit that what we know is much less than what we do not know" (Borel, 1657: 3–4).

The awareness that knowledge was on the brink of great change was a notion that could excite and inspire, but even more frequently amaze, bewilder or frighten, and one finds confirmation of this in many documents of the time. Is it not clear, wrote John Dryden, that in this last century a *new* nature has been revealed to us? The theme of novelty was pervasive in all of European culture and the word *new* appeared almost obsessively in the titles of hundreds of scientific publications in the seventeenth century: *Novum Organum* by Bacon, *Nova de universis philosphia* by Francesco Patrizi (1591), *De mundo nostro sublunari philosophia nova* by Gilbert (1651), *New Astronomy* by Kepler (1609), *Discourses on Two New Sciences* by Galileo (1638), *Novo teatro di machine* by Vittorio Zonca (1607), to name just a few (Thorndike, 1957).

Illustration

According to Panofsky (who published a major monograph on Dürer in 1943), the rigorous depiction of the natural world in the great paintings and engravings of the fifteenth to seventeenth centuries had the same importance for the descriptive sciences as the invention of the telescope and microscope had for astronomy and the life sciences. The illustrations in botanical, anatomical, and zoological texts were not simply additions to text but valuable given the absence of an adequate technical vocabulary (only achieved in botany, for example, over the course of the nineteenth century). Artistic collaboration in the descriptive sciences had a revolutionary effect.

For this reason let us return to Leonardo and his painterly interest in rendering all things *visible*. Many of his drawings of rocks, plants, animals, clouds, and the movement of air and water reveal scientific knowledge of living nature. Leonardo's anatomical drawings changed significantly after 1506, which is probably when he read Galen's *On the Use of Parts* and when the practice of dissection was becoming more common. For many years Leonardo studied in great depth the comparative anatomy of vertebrates, the flight of birds, and physiological optics, and made endless drawings of these subjects. He studied horse anatomy and made hundreds of drawings for the projected equestrian statue of Ludovico Sforza, the Duke of Milan (on which he began working in 1483) and the grand painting of the *Battle of Anghiari* (begun in 1503).

But Leonardo's curiosity was far greater than that of other sculptors and painters interested in artistic or superficial anatomy. He was a methodical and systematic observer and this approach was tied to his belief in the superiority of the *eye* to the *mind*, of careful observation of the real world to books and treatises. This was the source of both his greatest limitation (often cited by those who object to the mythic image of Leonardo the "modern scientist") and his one-of-a-kind greatness.

Leonardo's drawings remained unknown. The first woodcuts used to illustrate books printed with mobile characters date to 1461. The transition to engraving (Dürer's work among the most celebrated) and etching (a technique used by Rembrandt) led to a progressive refinement of the art of illustration. The first illustrated text on anatomy was Berengario de Carpi's 1521 commentary on Mondino de' Luzzi's *Anatomia* (de Luzzi was a professor in Bologna between 1315 and 1318). This was followed by *Isagoges breves in anatomiam* in 1523, and one of the greatest examples of the genre, *De dissectione partium corporis humani* (1545) by Charles Estienne (Stephanus Riverius). But the large and exquisite anatomical engravings by Andreas Vesalius in *De humani corporis fabrica* surpass all others for their precision and accuracy in depicting human anatomy and justifiably became the symbol of a radical change in the observation of the real world. Vasari attributed them to Jan Stephan van Calcar who was a student of Titian. One need only compare Vesalius's illustrations to medieval anatomical drawings to appreciate the quantitative leap they represented in the observation and representation of the human body. It is often observed that in 1543 Copernicus gave men a new image of the universe and Vesalius a new view of their bodies. Vesalius, who was born in Brussels to a family of doctors, studied in Louvain and Paris, and spent a great deal of time in Italy; he was called to Padua in 1537 to teach anatomy, and subsequently also taught in Bologna. In 1538 he published six anatomical sheets known as *Tabulae sex*. In 1543 he went to Basel to personally supervise the printing of the *De Fabrica* and the *Epitome* (also published in that year). He was only 28 years old when his masterpieces were published and he wrote in the Preface, "I am aware that because of my youth my work will carry little authority and be criticized because its Galenic principles do not correspond to reality [. . .] unless it finds an illustrious protector." That illustrious protector was none other than Emperor Charles V, who appointed Vesalius imperial physician and to whom the book is dedicated.

Vesalius patterned the content of the sections after Galen, and reaffirmed Galen's belief that the venous system was more important than the arterial to circulation. Like Galen, he too believed the veins originated in the liver. However, he energetically stated in the preface that he was distancing himself from the Galenic tradition because the master "was unaware of the numerous and substantial differences between the bodies of monkeys and men, with the exception of how differently the toes and ankles bend"; and that Galen, in the course of a single anatomical demonstration, "erred more than 200 times in correctly describing the parts, the harmony, the use and the function of the human body."

Contemporary scholars who have emphasized Vesalius's "Galenism" have not only tended to overlook these statements but also have not taken into account how fiercely the *De Fabrica* was criticized by traditional Galenists. Jacques Dubois (Jacobus Sylvius), Vesalius's teacher in Paris, became his greatest adversary and enemy, constantly referred to him as *Vesanus*, a play on words that meant "crazy or delirious," and accused him of poisoning the world of medicine with his work. Vesalius enthusiastically endorsed the need to fully merge clinical medicine with dissection (and surgery); he criticized the bookishness of medicine and fought for the union of direct observation and theory in the field. He proposed a new ideal of the physician, the professor of medicine, and the relationship in the "experimental" sciences between manual and intellectual labor. He felt that "disdain for manual labor" was one of the reasons for the degeneration of medical science. Doctors limited their services to prescribing medicinals and diets and had thrown aside the rest of the discipline to those "whom they call surgeons and consider nothing more than slaves." Once all manual procedures had been turned over to barbers, "not only did doctors lose their knowledge of internal organs but their cutting skills were also diminished." Doctors would not personally risk performing operations, yet those who did perform them were too ignorant to understand the written work of doctors. And so a reprehensible custom was established, with one person performing the operation and another describing the parts. The latter "presumptuously jabber from on high" and monotonously repeat things never directly observed but only memorized from books. Instruction was so poor that students learned less in that chaotic atmosphere than a doctor could have learned from a butcher in his shop" (Vesalius, 1964: 19, 25, 27). In 1555 the second edition of *De Fabrica* was published with some minor corrections. Vesalius was appointed physician to Philip II of Spain. He gave up the post in 1562 and died two years later in a shipwreck while returning from a pilgrimage to the Holy Land. He was returning to Padua to teach upon appointment by the Venetian Senate.

Vesalius's great book was also visible proof of an ever-growing collaboration between natural scientists and artists and engravers. Studies of illustration techniques and forms of this problematic collaboration in the field of anatomy as opposed to engineering, zoology, anatomy and botany, have emphasized the rapid and extraordinary transition that occurred in the sixteenth century from text-based to nature-based illustration. Two important books signaled the beginning of the tradition of modern herbals: *Herbarum vivae icones* (1530–6) by Otto Brunfels and illustrated by Hans Weiditz, and *De historia stirpium* (1542) by Leonhart Fuchs. In each case their novelty stems more from the illustrations than the text. In the preface to *Historia,* Fuchs wrote that the greatest care was taken "to represent every plant with its roots, stele, leaves, flowers, seeds, and fruit; moreover the omission of any modification of the natural form of a plant using shadows or other artistic techniques has been deliberate." At least in this case, there was some supervision; "we have not allowed artists to indulge their whims in order to avoid that the representations not correspond precisely to reality" (Fuchs, 1542: Preface). The first university botanical gardens were established in Padua and Pisa in 1544. In the early seventeenth century, "gardens" were second only to anatomical theaters as indispensable elements to insure the respectability of a university.

Far fewer encyclopedic works in zoology were undertaken. Some important "specialized" histories of animals (with important illustrations as well) include: *La nature et diversité des poissons* (1555) and *L'histoire de la nature des oyseaux* (1555) by Pierre Belon; *De piscibus marinis* (1554) by Guillaume Rondelet and *Dell'anatomia et delle infermitadi del cavallo*, a splendid treatise by the Bolognese senator Carlo Ruini. In addition to the work of Ulysses Aldrovandi, a major Renaissance contribution to the field was Konrad Gesner's *History of animals*. Though he died young, Gesner – a doctor and humanist – published books on botany, linguistics, the Alps, and alpinism. In 1545, at the age of 29, he published *Bibliotheca universalis*, a compendium of titles in Latin, Greek, and Hebrew. The *History* was published in five folio volumes and three volumes of *Icones* between 1551 and 1558 (the fifth volume was published posthumously in 1587) and numbered roughly 4,500 pages with over 1,000 woodcut illustrations made by artists in Gesner's native Zurich. The famous picture of a rhinoceros – to remain the model for all illustrations of rhinoceroses until the end of the eighteenth century – was based on Dürer, and reveals that artist's idea of the most famous of "exotic" animals as a scaly dragon (Gombrich, 1960). An extra small spiral horn behind the ears near the cervical vertebrae vanished from illustrations only in 1698.

Gesner ignored comparative anatomy and classified animals alphabetically (hence *Hippopotamus* comes between *Hippocampus* and *Hirudo* or leech). Each animal was described in often lengthy chapters (176 pages in folio for the horse and 33 for the elephant) that were divided in sections designated by letter. The sections included the animal's name in different ancient and modern languages, its habitat and morphology, diseases, behavior, function and breeding, edibility (when appropriate), usefulness to medicine, etymology, and proverbs.

On the subject of illustration and the "limitations of realistic portrayal," Gombrich certainly is correct in sustaining that a representation that already exists "will always exert an influence on the artist even when his goal is to accurately depict reality" and "a visual image cannot be created from nothing." Moreover, the comparison of a drawing of a lion and a porcupine by the Gothic architect Villard de Honnecourt and a Dürer watercolor of a rabbit reveals something that Gombrich too has pointed out: between the fourteenth and the sixteenth centuries a significant stylistic change occurred. Artistic "style" lost its formality and "learned to adapt with sufficient ease" to the subjects it rendered (Gombrich, 1950). This change had a significant impact on the development of scientific knowledge.

New Stars

In 1609 Galileo Galilei began observing the night sky with a telescope and then published his observations in Venice, on March 12, 1610, in a short book entitled *Sidereus nuncius* (*Starry Messenger*). Galileo described the surface of the moon as not "uniformly smooth and perfectly spherical as countless philosophers have claimed about it and other celestial bodies, but rather, uneven, rough, and full of sunken and raised areas like the valleys and mountains that cover the Earth." Looking more closely, he observed that the boundaries between dark and light regions were uneven and sinuous, and points of light that appeared in the shadowy region of the moon merged with the light regions. Didn't the same thing happen on Earth? The highest mountain peaks are illuminated by the dawn's light while the plains below remain in the shadow. And once the sun has risen, the sunny mountains ultimately join together with the plains. The landscape of the moon is therefore *like* the landscape of the earth. The Earth has characteristics which are *not* unique in the universe. The celestial bodies, at least in the case of the moon, are not by their nature different and do not possess the characteristics of absolute perfection that an age-old tradition attributed to them. And there are many more stars than can be seen with the "naked eye." The telescope revealed a sky populated by countless heavenly bodies. It showed the complex structure of known constellations, and uncovered the nature of the Milky Way: "what we observed in the third place is the essence, or rather the matter of the Milky Way that, thanks to the telescope, has been carefully examined, and the mysteries that have plagued philosophers for centuries can now be solved by virtue of what we are able to see with our eyes and so are freed from verbose discussion." The ability to see the dark sections of the moon's surface led Galileo to conclude that sunlight was reflected

from the Earth to the moon and back. As for the stars, he finally concluded that there was a great difference between fixed stars and planets: stars still looked like bright points surrounded by "sparkling rays" but did not appear larger through the lens of the telescope, whereas planets looked like perfectly round and definitely bounded globes, like little moons and were much magnified by the telescope. So the distance between the fixed stars and Earth was incomparably greater than that between the planets and Earth.

Galileo also presented another fundamental discovery in the *Sidereus nuncius*, the pages of which still today resonate with the sense of trepidation that accompanies any vision of a new truth. On the night of 7 January he observed three small bright stars next to Jupiter, two to the east and one to the west of it. The following night their position had changed and they were all west of Jupiter, and on the 10th two of the stars were to the east and the third seemed hidden behind the planet. On the 12th, after two hours of observation, Galileo watched the third star reappear, and on the next night there were four stars: these were Jupiter's moons or satellites (now known as Io, Europe, Ganymede, and Callisto) and called the "Medicean stars" by Galileo in honor of Cosimo II.

The revolutionary nature of Galileo's discoveries was recognized by his contemporaries. In a poem dedicated to "our century's prince of mathematicians," Johannes Faber declared that Vespucci and Columbus who had sailed uncharted seas should make way for Galileo who had given all of mankind new constellations. The comparison to great geographical discoveries and New World voyages was repeatedly made. In England, William Lower wrote to his friend, Thomas Hariot, that Galileo had accomplished something even greater than Magellan who had also opened up unexplored territory. In a 1612 work describing the intellectual world in which he lived, Francis Bacon praised "the industry of mechanics, the zeal and energy of certain learned men who so recently, by using new optical instruments like sloops and small vessels, had begun new enterprises with the wonders of the heavens." Their undertaking, he continued, should be regarded as "something noble and worthy of mankind and those brave individuals should also be praised for their honesty because with candor and clarity, they methodically accounted for each step in their research." Though the Lord Chancellor did not accept Copernican cosmology, he was a great philosopher. The English ambassador to Venice, Sir Henry Wotton, though a man of vast and refined culture, was not. The day *Sidereus nuncius* was published he sent a copy to the king with a promise to soon send him a telescope and his words clearly conveyed the challenge that Galileo's observations posed to traditional cosmology: "I send His Majesty, together with this letter, the strangest news ever before heard on earth. By this I mean the enclosed book by that mathematics professor at Padua [. . .]. He hath first overthrown all former astronomy [. . .] and next all astrology [. . .]. The author runneth a fortune to be either exceedingly famous or exceedingly ridiculous."

There was no shortage of bitter controversy, tenacious rejections, obstinate shows of disbelief from pro-Aristotelian academic quarters. The celebrated Cremonini, a colleague and friend of Galileo at Padua, did not believe Galileo had seen anything, objected to those "spectacles" that "muddle one's head," and berated Galileo for having gotten involved "in all these intrigues." Giovanni Antonio Magini, an astronomer at Bologna, took a hostile and malicious stance. And when Galileo was in Bologna in April 1610 to try to prove his discoveries to the faculty, Martin Horky, who later became a vehement enemy, wrote to Kepler saying that he "had tested Galileo's instrument in many ways, with both inferior and superior things; while remarkable with the former it fails with regard to the heavens because the fixed stars appear exactly the same."

Eventually Kepler acknowledged Galileo's work, and after initial skepticism so did the Jesuits in Rome. Galileo had won, because in order to win over the final, unyielding objectors and silence the professors who rejected the moon's mountains or Jupiter's satellites on the grounds of logic and metaphysics, not even "the sworn testimony of the stars themselves" would have sufficed, as he later wrote. The reality of the universe had been expanded through the use of a mechanical instrument that was capable of assisting, perfecting, and refining the human senses. For the men of his day, Galileo's astronomical observations not only signaled the end of one world view but represented the birth of a new concept of experience and truth. "Seeing is believing" and the evidence had at last broken an endless circle of dispute.

The Discovery of an Unknown Visual World

In the seventeenth and eighteenth centuries there was as great a fascination with the *small* and infinitely small as with the *large*, such as endless distances and an apparently infinite universe. The concept of nature as a sort of *plenum formarum*, an infinite hierarchy of forms, a complete and endlessly graduated scale of Being (one of the great idea-forces in philosophy for the last two centuries) seemed in itself to imply the existence of a minute and invisible reality which necessarily escaped the limited capacity of the human eye. In 1664 Henry Power published *Experimental Philosophy, Containing, New Experiments Microscopical, Mercurical, Magnetical.* He believed that "new dioptrick discoveries" were proof that the smallest bodies man could see with the naked eye were but "a

proportional average" of two undetectable extremes. Even the idea that nature could be explained by studying its corpuscular or cellular structure implied an interest in instruments that could magnify the natural range of man's senses. The inhabitants of Bacon's *New Atlantis* (1627) had visual aids superior to the spectacles and lenses in use at the time and that allowed them to "see small and minute bodies perfectly and distinctly, such as the shapes and colors of small flies and worms, grains and flaws in gems, and observations of urine and blood, that cannot otherwise be seen" (Bacon, 1975: 861).

Yet in the history of the microscope and its contribution to science there is no single dramatic date that compares to 1609 in the history of the telescope. It has often been noted that the telescope exerted its influence within the framework of an established science deeply rooted in antiquity. The microscope, on the other hand, was introduced at the beginning of a long process that culminated in new sciences. Histology and microbiology were only established in the eighteenth century. The word *microscopium* was first used in a letter from Johannes Faber to Prince Federico Cesi (April 13, 1625). Cesi and three friends had begun to study science in 1603 as young men, and were the nucleus of the *Accademia dei Lincei.* The first "separate" book on microscopy was the *Centuria observationum microscopicarum* (1655) by Pierre Borel.

The early seventeenth-century microscope was a tubular instrument with a lens at one end and a place to put an object on a glass slide at the other. Objects were magnified about ten diameters. The first members of the *Lincei* used instruments of this kind, and indeed the name of their academy refers to the acute eyesight of the lynx. In 1625 Cesi added plates of bees to the *Apiarum*, and these were published in Stelluti's *Persio tradotto* (Rome, 1630). This was most likely the very first printed illustration of objects seen with the use of a microscope. Stelluti insisted that what could be seen in the plates "was unknown to Aristotle and every other naturalist." In addition to an image of a "walking" bee, there were illustrations of its wings, tongue, "hairy eye," and legs. In 1644 in Palermo, Odierna studied the compound eye of different insect species. Two years later in Naples, Fontana completed a study of vinegar eels.

The so-called "classical microscopists" – Robert Hooke, Antony van Leeuwenhoeck, Jan Swammerdam, Marcello Malpighi, and Nehemia Grew – belonged to the next generation. The instruments they used could enlarge objects up to 100 times, though resolution was mediocre. The compound microscope (not used by Leeuwenhoeck) consisted of lenses fixed at the ends of cardboard tubes. The tube of the eyepiece was fitted inside that of the objective and to focus one slid the tubes up and down. Microscopes of this type (made in Italy by Campani) were widely known. The type described by Hooke had a screw-mechanism for focusing and was made up of a large cylindrical body: the objective had a biconvex lens regulated by a diaphragm and the eyepiece was made up of a flat-convex lens and a small biconvex lens (the mirror that cast light upwards was not invented until about 1720). These microscopes (as well as Leeuwenhoeck's incredibly minute lenses) were not limited to magnifying the known world (like the bees enlarged by Cesi) but opened up a new and unexpected world of minerals and organic tissue that had structures; a world inhabited by living organisms invisible to the naked eye.

Let us briefly return to the subject of illustration and its importance to science. Like Vesalius's work one century earlier, it was the fine engravings made by the celebrated architect Christopher Wren for Hooke's *Microscopia* (1665) that set the work apart from others of the same period. And Hooke's contemporaries included Marcello Malpighi, the author of *De pulmonibus* (1661), who was certainly a better *biologist* than Hooke. For a century and a half it had been acknowledged that the art of illustration had much to offer the sciences, yet the first generation of microscopists seemed hardly to notice. The 32 fine plates in the *Microscopia* (still used in nineteenth-century manuals) illustrated the potential of the medium (Hall, 1954).

The point of a sharp needle, fleas, flies, ants, lice: Hooke not only observed objects never before observed by others, but he described what he saw with unusual precision and passion for detail. He described the outer covering of a fly's eye as supple and transparent, and like the human cornea. When the eyeball and dark, mucousy substance was removed Hooke noted "how transparent the covering is, like a thin layer of skin with many small holes in the same arrangement as the external prominences." It was clear that this curious apparatus was the organ of sight for flies and crustaceans (Hooke, 1665: Preface). The term *cell* was first used in the title of his eighteenth observation, "Of the Schematisme or texture of cork, and of the cells and pores of some other such frothy bodies." He used the term because of the resemblance to the cells of the honey-comb, and so it is a mistake to consider him the discoverer of the cell.

Hooke, a scientist in the Baconian tradition, often emphasized the notion of broadening the territory of the senses. The telescope had opened up the skies to observation and revealed "a great number of new stars and new movements unknown to ancient astronomers." At the same time the once familiar Earth now seemed new, and every observation of its matter revealed "as great a variety of organisms as once we counted in all of the universe." New instruments permitted both the examination of the visible world and the discovery of unknown worlds: every notable improvement of the telescope and microscope "produces new worlds and lands unknown to our sight" (ibid.: 177–8).

Over the course of several meetings of the Royal Society in 1677, Hooke

read from a 17–page letter by Antony van Leeuwenhoeck to that illustrious academy. The author was neither a natural philosopher nor a scholar. Leeuwenhoeck, chamberlain to the aldermen of Delft in southern Holland, had single-handedly manufactured hundreds of tiny biconvex lenses (smaller than 2.5 mm. in diameter) which, placed in a metal mounting, worked as simple microscopes. His remarkable skill as an optician (one of the lenses he developed proved to be superior to any other known simple lens) together with unsatiable curiosity led him to examine spermatozoa and red blood cells and identify protozoa and bacteria. In September 1674 he described the movement of the organisms in a drop of water [. . .] swift and marvelous to see and I judge that some of these little creatures were above a thousand times smaller than the smallest ones I have hitherto seen in cheese or mould." Small animals even live inside the human body. In October 1676 he described protozoa: "it is like seeing, with the naked eye, little eels that twist and turn against each other and the water seems to be alive with these different little animals; this for me, of all the marvels I have observed in nature, is the grandest of all."

The New World

"In the Indies everything is marvelous, surprising, different, and on a larger scale than anything in the Old World," wrote José Acosta. Columbus, Magellan, and many other early modern explorers and navigators, had all seen with their own eyes – like Galileo, Hooke, and Leeuwenhoeck did later – things never before seen. The discovery of new lands also challenged the superiority of antiquity. Simple mariners – declared many – were able to *see* the opposite of what Greek philosophers and Church Fathers had declared with regard to the inhabitability of tropical areas, the existence of the Antipodes, the navigation of the Oceans, and the impassability of the Pillars of Hercules.

The New World had unknown plants (corn, manioc, potatoes, beans, tomatoes, peppers, squash, avocado, pineapple, cocoa, tobacco, rubber trees) and unknown animals (turkey, llama, lynx, puma, condor, jaguar, tapir, vicuña, cayman). There were descriptions of new animals and plants in *Historia general y natural de las Indias* by Gonzalo Fernández de Oviedo y Valdés, who for over forty years was the gold inspector in Santo Domingo. In early sixteenth-century charts and maps, the new continent was shown to be inhabited by unicorns, dog-headed beings, and men with eyes, noses, and mouths on their chests: Oviedo refrained from such descriptions of monsters and imaginary creatures. He believed in one nature that assumed different forms in different parts of the world; plants that are dangerous in one location are not in another, man can have white or black skin, tigers that are agile and swift in Europe are "heavy and slow in His Majesty's India." Even the Jesuit Acosta described the characteristics of soil, minerals, volcanoes, metals, plants, animals, fish, and birds in the *Historia natural y moral de las Indias* (1590). The New World is inhabited by "many animals never before seen by the Greeks, the Latins, or any other people of *this world*." The great mathematician Thomas Hariot, who admired Galileo and corresponded with Kepler, touched on a similar theme in a 1588 pamphlet entitled *A Briefe and Troue Report of the New Found Land*. In Italy, Cesi acquired the manuscript of *Tesoro messicano* or *Rerum medicarum Novae Hispaniae thesaurus*, a collection of exotic plants and animals based on the report of King Philip II's physician, Francisco Hernández. After a series of editorial mishaps, Stelluti published the work in 1651.

Acosta also discussed at great length the men and women of the New World and their customs. The book, translated into English in 1604, Italian in 1606, and Dutch in 1624, was at the center of a great cultural debate in Europe from the middle of the sixteenth century to Vico. Many difficult questions were posed, such as how to reconcile Bibilical narrative with the fact that men lived in places remote from the center of the Judeo-Christian world; whether the indigenous people of the Americas descended from once-civilized races that had fallen into barbarism; did the different races and peoples in different parts of the Earth have different origins; how can one explain that all men are directly descended from Adam; did the Great Flood affect all the lands on earth, or was it a local disaster, and if local then is the Biblical account confined to one population in one location only; how can one explain the existence of plants and animals so different from those known; how did the New World animals get on and off Noah's Ark; why are there no survivors of these species in the Old World; is it possible that after the sixth day of creation God went on to create the New World; and most importantly, how did Old World peoples reach the New World?

Freethinkers of every sort used the discovery of the New World to express their doubts about the validity of the Biblical account and advance the type of sacrilegious questions that were popular in the late seventeenth and eighteenth centuries, calling them Lucretian, Spinozoan, and materialist. Cardano implicitly asserted the spontaneous generation of humans from matter. The Aristotelian Andrea Cesalpino explicitly stated that "all animals, including man, may have originated from decaying matter," and in his opinion, this was more easily seen in torrid and lush zones like the New World. Giordano Bruno believed that the presence of animals and men in the New World did not constitute a problem and was proof that each land produced its own kind of animals. It was

absurd to assume that the peoples of the Americas were descended from Adam, and "indeed, there was not just one first wolf or lion or ox that begot all the wolves, lions, and oxen that live all over the world, but different lands produced their own kind from the origin." The debate between polygenists and monogenists (such as Acosta) was destined to be sensational.

Paracelsus would not attribute human characteristics to New World populations. Like giants, gnomes, and nymphs, "they resemble man in every way except for their souls." Like "bees with their king and wild ducks with their leader, they live not according to the order of human laws but follow their innate nature." Even the humanist Juan Ginés de Sépulveda, among other writers, philosophers and travelers, portrayed indigenous Americans as a subspecies capable of every sort of "abominable infamy." Montaigne presented a radically different view of Brazilian tribesmen in the *Essays* (1580): "it is neither possible nor just to take the point-of-view of Europeans or Christians when judging non-European peoples. Humanity expresses itself in an infinite variety of forms and "each claims the other uncivilized" (Montaigne, 1970: 272).

Discussion of "good and wicked savages" was interwoven with events in biology and political philosophy. Up until Buffon, the abbot Corneille de Pauw, and the Romantics, there was no doubt that all *nature* in the New World was "degenerate", "decadent", or even "inferior." Hegel described New World fauna in *Philosophie der Geschichte* as smaller, weaker, and less virile.