"The Scientific Cosmos of Columbus: An Overview", by Charlotte M. Porter
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"I intend to make a new sailing chart. In it I will locate all of the sea and the lands of the Ocean Sea in their proper places." - Christopher Columbus

Christopher Columbus (1451-1506) set sail in 1492 as Christian rule returned to Spanish lands. At the same time that Spain became a nation-state, more people wanted to read. Prior to the advent of printing, books were in manuscript form. They were often difficult to use and copies were limited. Although the pages of these books were sometimes beautifully illustrated or illuminated, the handwritten process of producing the text perpetuated errors. Mistakes were introduced: sections were left out. Illustrations parted company with their texts, and sometimes the results were completely backwards. A 13th-century fortune-telling tract at the University of Oxford, for example, shows Plato coaching Socrates.

The rapid growth of printing forever changed the nature of books. By 1480, there were printing presses in over one hundred towns throughout Europe. Italy could boast fifty; Spain had eight. By 1500, the number of European presses had almost tripled. These presses printed 35,000 editions of well over 10,000 different texts. For the first time, people of ordinary means could acquire their own books. Travel books were best-sellers. Columbus, for one, owned and carried with him a copy of the 1485 edition of Marco Polo's Travels. At the lay level, works called pandects brought together quotes from older geographical manuscripts with the latest word from world travelers. The two did not always agree. In part, Columbus intended his proposed chart to create a better fit between modern experience and ancient authority.

Columbus was a man of action. He was also a man of thought, and his voyage to the Caribbean culminated more than a decade of planning. His attention to cosmology was not limited to the shape and size of Earth. As the diary for the first voyage shows, the very length of the voyage forced him to consider other factors of nature, meteorological conditions, natural history, and human health. His expressions reflected scientific ideas of his time, some of which will be reviewed here. Upon arrival, Columbus fully expected to find novelty, new plants - spices, dyes, and medicinal herbs. Despite his expectations, however, nothing in his cosmology, his reading or nautical experience truly prepared him for the West Indies.

In December of 1491, Columbus came to the Spanish court set up outside the besieged city of Granada. The Italian navigator from Genoa had wasted no time. The troops of Ferdinand and Isabella were waiting outside the walls for the Moors' expected surrender of this, their last stronghold. Columbus had come to Granada to seek support for a voyage across the Atlantic Ocean. His proposal to reach Asia by sailing west was novel in its boldness. By contrast, his ideas about the world - the Earth and its waters - were ancient.

By April of 1492, the victorious Spanish monarchs at last agreed to help Columbus get under way. Columbus and his backers put up some cash. The Spanish crown provided treasury funds and the use of three ships from Castile. Columbus acquired the title Admiral and was to receive ten percent of the profits from sales of any "pearls, precious stones, gold, silver, [or] spices" obtained. Since pearls and spices were of organic origins, natural history identification obviously would be key to the financial success of this venture.

The listing of spices with gems and precious metals was no mistake. Since Roman days, many non-native medicinal and cooking herbs were "controlled substances," and plant traffic on overland routes from the Middle East to Europe was subject to check-points. Fifteenth-century advances in navigation, marine transportation, and the European discovery of exotic island sources put a new face on the spice trade. For a time, however, supply did not catch up with demand, and novel food flavorings commanded high prices.

In 1492, black pepper, the newest spice from the East Indies, was still hot business for Portugal. As Columbus set sail, peppercorns, the dried berries of the tree Piper nigrum were worth their weight in silver. Pepper was used to purchase land, pay off mortgages, and buy prestigious coats of arms and to settle custom duties, rents, taxes, and even court fines. Besides pepper, cane sugar was a second recently acquired taste. Obtained from a large Oriental grass, Saccarum officinarum, cane sugar had been introduced to the Mediterranean region by the Arabs. Quite rapidly, plantations established on the Canary Islands vastly increased world supplies of sugar.

Prior to black pepper and cane sugar, Europeans flavored their foods with salt, onions, and garlic. They satisfied a sweet tooth with beet sweeteners, sorghum, and honey. Cabbage, lettuce, chard, and endive were vegetable staples. For those who could afford them, meat, poultry, and game dishes were the courses of choice, often served at the same meal. The use of plant stimulants - caffeine, cacao, coca, and nicotine - was unknown. Maize, tobacco, beans, squashes, pumpkins, peanuts, sweet potatoes, peppers, lignum vitae, and manioc, to name just a few native American species Columbus saw in use, were not known to Spain or to any other part of the Old World.

Columbus appreciated new plant materials, and his diary relays heady excitement about Caribbean prospects. For October 19, 1492, he noted, "And I even believe that there are among them many plants and many trees which in Spain are valued for dyes and for medicinal spices; but I am not acquainted with them, which gives me much sorrow." Surrounded by natural bounty, Columbus ironically was at a loss to identify what he had come for. The fact that his crew did not include a plant doctor, herbalist or gardener mattered. The flora of the Caribbean was a new world to Europeans, or more precisely, Graeco-Islamic science.

Old World Teachers

For eight hundred years, works of science had made their way to Moslem Spain from other parts of the Islamic world. In Spain, they were saved and studied, along with the teachings of the ancient Greeks and Romans. The defeat of the Moors at Granada on January 6, 1492, ended Moslem rule in Spain and Spain's unusual role as a curatorial center for generations of scientific manuscripts. After ousting the Moors, Isabella and Ferdinand occupied their citadel, the Alhambra. There, the Catholic monarchs asserted their rule in a space defined by the signs of ancient pagan science.

Built in earlier centuries, the Alhambra is resplendent with geometry, the mathematical heritage of Greece. Throughout the vast halls, apartments, and whispering galleries, the details of the smallest tiles catch the eye of even the most casual viewer. For a Renaissance visitor coming like Columbus to curry favor, these circles, cycles, and spiraling epicycles were familiar designs with a familiar message. Derived from preceding centuries of Greek and Arabic cosmology, they are the decorative expressions of a scientific world system based on spheres.

Much of the work of 15th-century science was astronomy, and much of this work was done at night. Astronomical data were necessary for navigation, calendars, and time-keeping. By far the best instrument for these computations was the Islamic astrolabe, an intricate model of the night skies. Although the astrolabe is a series of flat plates, its realm of reference is spherical. On land, the astrolabe was a favorite instrument of astrologers. At sea, aligning the serial plates of this complex device proved unwieldy for navigators, and 16th-century sailors passed over the astrolabe for the more handy sextant. For the mathematically trained astronomer, astrologer or seaman, interpretation of the astrolabe only made sense in a spherical cosmos.

On a more intimate level, the circles and cycles of six centuries of Arabic interpretation also informed 15th-century health practices. Unlike the powerful Sunni branch of Islam, the Shiites did not forbid drawing the human body. As a result, Persian charts still exist which permit us to see, as well as to read, their analyses of physiology. Because of the taboo against dissection of cadavers, the information these visual charts impart is general and imprecise. The images, geometric and stylized, present the human body as six discrete systems - muscles, bones, nerves, arteries, veins, and reproductive organs. Arteries and veins trace their independent courses as gracefully as the decorative flourishes on Moorish ceramics; by contrast, the bones of the skull and skeleton look laid out heavy and flat like sections of pavement. Each system is shown in the abstract and complete unto itself. People of the 15th century looked at their world and their bodies through the words of Pliny, Ptolemy, and Avicenna, to name but a few enduring authorities. They also relied upon astrology to integrate their bodies and bodily functions into the larger closed and spherical cosmos.

A World of Spheres

"...the rounded appearance of a perfect sphere."

After 1469, Columbus - or any of his detractors - could read this statement about Earth in one of the first books to be printed after Gutenberg's Bible. The author was Pliny the Elder (A.D. 23-79), a Roman official whose chatty and voluminous encyclopedia gave natural history both its name and broad scope. In Pliny's worldbook, the appearance not only of Earth, but also of the entire universe was round.

Pliny's explanations were ultimately derived from the spherical cosmology developed by the Athenian philosopher Aristotle (384-323 B.C.). Aristotle was not an astronomer or star watcher, but he was concerned with observable natural changes. Discontent with the idealism of his teacher Plato (427-347 B.C.). Aristotle attempted to explain the events of nature. For this reason, his thought strongly influenced natural sciences of later centuries. Studied as the organon or tool of knowledge, concepts attributed to Aristotle guided Medieval scholasticism and Renaissance academic thought.

The Aristotelian universe familiar to the Renaissance was spherical and finite and it was relatively small. On a clear night the outer starry limit was visible to the naked eye. The simplicity ends here, however, as Aristotle developed a geometric scheme suggested by Eudoxus (409-356 B.C.) of Cnidus. Day and night, the rising and setting of the stars, required twenty-eight moving spheres. Central to the system is a spherical moving Earth; outermost is the rotating sphere of stars. In between, the Moon and Sun, also spherical, revolve around Earth on circular paths that do not change. Their observed paths are each the composite motions of three spheres; one for daily or diurnal rotation, one for annual motion, and one for supposed motion in latitude. Each of the five known planets required a similar set of three spheres. This system of motion was eternal, unchanging, and uniform.

Unfortunately, observation did not completely support this model. Astronomers had to postulate a fourth sphere to account for a most troublesome type of planetary movement, retrogression. Viewed from Earth, the wanderers, as the Greeks called the planets, did not move on perfect circles like the Sun. Instead, they traced out arcs, stopping at some points and looping back at others. Centuries of attention did not resolve the issue of retrogression.

At the time of Columbus, the tables used for planetary positions were grossly inaccurate. Drawn up in the late 13th century under Alfonso the Wise in Spain, they failed to provide reliable information. By the 15th century, calendrical reforms were long overdue. For example, the values used for months and years were too imprecise for the dating of Easter. Wishing to free their age of the errors of the past, humanist astronomers George Puerbach (1423-1469) and Johann Miller Regiomontanus (1436-1476) advocated a return to Greek sources.

The well-chosen point of return for these Renaissance researchers was the corpus of work by the Alexandrian astronomer Claudius Ptolemy (85-165). Ptolemy quantitated the cosmology of Aristotle with the mathematics of later Hellenistic astronomers. His synthesis created a universe defined by sizes and distances which gave basic structure to the 15th-century world.

An unequalled observer of the night skies, Ptolemy catalogued over one thousand stars or virtually all the points of light visible to the naked eye. During the day, he studied in the greatest scientific library in the ancient world. Ptolemy reviewed astronomers of the second century B.C. who, unlike their Athenian predecessors, had access to three thousand years of Babylonian star records. To improve the fit between this remarkable data base and earlier theory, Hellenistic mathematicians had added more revolving circles called epicycles, deferents, and eccentrics. Ptolemy reworked these computations into a cogent system, using a series of geometric comparisons based upon Earth's radius.

Ptolemy did not stop with astronomy. Much of the astrology, as well as the geography of the early Renaissance, was based upon Ptolemy's achievements. Summaries of Ptolemy's writings were translated into Arabic during the ninth century and into Latin during the 12th century. His astronomy was known, mostly through commentaries, under a garbled Arabic title as the Almagest. In 1245, the Almagest was popularized in verse as Image du Monde, later rendered as the much printed Mirror of the World.

How big was this world? By the 13th century, the radius used for universe - the distance from the central Earth to the outermost sphere of stars - was roughly 65,357.500 miles. Of known cosmic dimensions, the universe was thus defined and unchanging space with things, Columbus's phrase, "in their proper place." It was a closed and ordered plenum, to use a scholastic term of Aristotelian physics.

As Columbus set sail, the beginnings of a new world system was quietly taking shape in the mind of a Polish student named Nicolas Copernicus (1473-1543). Copernicus began to regard the Sun, rather than the Earth, as the center of the orbits of the planets. Unlike Ptolemy, Copernicus was not an assiduous observer of the night skies, often cloudy over Cracaw. He was a close reader of the Almagest, and he picked up on Ptolemy's notation that substituting the Sun for Earth in some cases gave a better fit between observation and model. With this mathematical insight, the Catholic cleric diligently computed an alternative system, still spherical and closed, in which Earth and the planets moved around a central stationary Sun. De Revolutionibus, the difficult book that presented his mathematical comparisons, was published in 1543, thirty-seven years after Columbus' death.

The Sphere of Earth

"The Earth is small; 6 parts of it is dry land."

The Earth familiar to Columbus and his corespondents was not a planet. As Columbus's remark suggests, he believed that most of the terrestrial sphere was earth, the element for which it was named. The other three elements - water, air, and fire - were each to be found in their proper or natural place. The cosmic center, earth, was covered by an incomplete wrapper of moisture, water. Water commingled with and was inclosed by a spherical atmosphere of air. Air, in turn, was surrounded by the region of fire. While loose earth fell down to its proper place and water sought its own level, air and fire rose to their respective regions. Fifteenth century Aristotelian physicists used the terms gravity and levity to describe these motions.

Ionian philosophers had reasoned that the interplay of the four elements accounted for the flux and change of terrestrial events. To their material framework, Aristotle added cause to guide or direct events. From the growth and death of living things to seasonal patterns of weather, change was confined to the region below the Moon. Generation, corruption and decay could happen nowhere else since the rest of the universe, including Moon, was made of an immortal fifth element called ether. According to Aristotle, there was another important difference, too. In contrast to the unchanging or uniform spherical motions of celestial bodies, the ephemeral movements that took place on Earth were rectilinear. Two kinds of physics, then, were required to comprehend motions on Earth and in the heavens.

The challenge for Columbus was to move his ships along straight line segments on a spherical surface. Stated a different way, his voyage represented a specialized type of rectilinear motion, maritime navigation. He hoped to cross an ocean of unknown size on a sphere of known size. Hellenistic astronomers had figured Earth's diameter to be about 6,500 miles. Since the Ocean Sea was not the only sea, it had to be far less than 6,500 miles x 1/7 x (pi) or about 2,925 miles across, and Columbus may have considered it to be even smaller.

Although globes showing the night skies were common, globes showing Earth were not. As Columbus planned his trip, Martin Behaim (1459-1507) used similar reasoning to construct the first globe or spherical map of Earth. On Behaim's globe, there would be no room in the Ocean Sea for two more continents, North and South America. Why was his concept of the western hemisphere, or more precisely, the picture of the Ocean Sea so small? The length of a degree Columbus, Behaim, and their contemporaries were using was not correct, or to put it another way, they placed the equator too far to the north.

Even without seeing Behaim's globe, few people in 1492 believed Columbus's ship would sail off the ends of the Earth. They simply did not know what lay beyond the Pillars of Hercules, rocky summits on each side of Spain's Straits of Gibraltar. Since ancient Greek times, these pillars had marked the traditional western limit of safe ocean sailing: ne plus ultra. After Columbus's achievement, this motto was shortened to a smarter plus ultra. Columbus's personal view of the risks his voyage involved, of the chances he was taking, is a matter of interesting speculation. As John Webster later commented, "not chance but the heavens and stars govern the world."

The Course of the Body

Fifteenth century Europeans embraced the astrology basic to Arabic science. In their world, organs of the body were each associated with a star group or constellation of the zodiac. These twelve star groups highlight the ecliptic, the annual path of the Sun as seen from the Earth. The twelve constellations, better known today as signs, were believed to influence parts of the body.

The functions of these parts were explained in a tome compiled by Ibn Sina (d. 1037), a Persian-speaking scholar of Bokara known to the Latin west as Avicenna. During the Middle Ages, European medical instruction relied almost exclusively upon Avicenna's Canon of Medicine. The advent of printing briefly gave strength to Avicenna's authority, and after 1480, many different printed editions of the Canon were in circulation at European universities.

Some Christian readers, however, were tired of balancing Graeco-Roman and Islamic traditions. In 1492, one Italian professor found enough errors in the Canon to fill twenty chapters of his own book. In Italy, medical schools began to shift away from both the Canon and Arabic medicine. Spain followed, and in 1565, the University of Alcala de Henares abolished instruction based on the Canon. This trend was part of the humanist return to original Greek and Roman texts.

In the 1490s, the inside of the body was still as new to artists as the Caribbean was to cartographers. Many artists had mastered the outside or surface anatomy of the body, but before 1498, even the drawings of Leonardo da Vinci (1452-1519) do not show a confident familiarity with internal organs. This lag is particularly interesting in Italy, where for three hundred years, autopsies of crime victims and criminals had taken place before courts of law. With the help of artists, anatomists were soon to chart a new course of the body.

By the end of the 15th century, the study of bodies rather than books broke with earlier medieval and Islamic strictures against dissection. At the medical schools, an assistant or ostensor cut open the corpse, while the medical professors read lectures from a text. These classes were held outside during warm weather to minimize the unpleasantness of working with decomposing bodies. The lay public of the early 16th century had the rather unusual opportunity to view dissections and hear debates about the accuracy of ancient anatomical texts.

Critics wanted better access to original Greek and Roman sources, and perhaps the most important source to them was Galen of Pergamon (A.D. 129-199), the last important medical author to write in Greek. Galen's lectures guided generations of readers to the form and function of internal organs with the versimilitude of firsthand observation. As Renaissance anatomists would uncover, Galen's discussions of human biology, however vivid, were not always based on patients. The six-lobed liver he described for humans was actually that of a dog.

Dispensing with pedagogical tradition, Andreas Vesalius (1514-1564) began performing his own dissections on human cadavers before university students in Padua. The young professor intended to purge mistakes the Canon of Medicine and Arabic commentaries had introduced to Galenic instruction. Repeated dissection of human cadavers not only showed Arabic mistakes, but also revealed two hundred of Galen's errors. To prove his findings, Vesalius prepared for students boldly pictured anatomical cut-aways. Widely plagiarized, these plates upset the academic notion that illustrations degraded scholarship. The awkward squatting figures shown in Persian medical charts immediately became obsolete images.

Vesalius published De Humani Corporus Fabrica in 1543, the same year as Copernicus's De Revolutionibus. The woodblock illustrations for De Fabrica, perhaps the work of Jan Stephan van Kalchar (1499-1549), brought science, art, and instruction together in an unforgettable way. Cadavers model their organs in classical poses. Despite their various stages of dissection, these bodies are people in full possession of their dignity. Criminals and crime victims alike, they stand fearlessly in beautifully rendered landscapes. The fabric of their flesh reduced to mere strings, they are also freed from the weight of tradition.

Vesalius, like Columbus, was looking and doing as well as studying books. He, too, sufficiently trusted the evidence of his senses to discredit over fourteen hundred years of medical dogma. As the frontisplate in his great book shows, he also trusted those around him in public demonstrations to recognize the truth of his words in the truth of his actions. As he peeled away layer after layer of tissue, he was literally opening a new world for all to see. There would be no going back.

Vesalius was a professor of surgery, but during Columbus's lifetime, medical schools were closed to students of surgery. Barber surgeons, not doctors, routinely set bones, cut out tonsils, and wired in loose teeth. Their diversified skills were considered a trade, rather than an art, and their practices were regulated by city licensing. Although they lacked formal medical training, the best barber surgeons were guided by a code of ethics. "It is necessary that the surgeon be skillful, of a moral nature, and neither too slow nor too fast in his work," urged Heironymus Brunschwig (c. 1410-1512) in 1497. Less enlightened surgeons cut according to their patients' horoscopes.

The status of European surgeons improved during the frequent military campaigns that characterized the 15th century. Surgeons gained humane insight and new prestige on the battlefield. Many army surgeons were brave, but the tools of the past could not prepare them for the weapons of the future. The introduction of gunpowder from China forever changed warfare and the wounds surgeons treated. At first, the effects of the sulphur were feared more than the penetration of the shot. The conventional antidote to sulphur was cauterization of the wound with acid. This ghastly treatment caused violent pain and was eventually abandoned on the urging of Ambroise Pare (1510-90), perhaps the most influential military surgeon of the 16th century. Although unschooled, Pare advocated the importance of anatomy to surgery and pioneered the design of a nasal prosthesis and artificial hand with articulated fingers. To the chagrin of academic doctors, this long-lived and prolific surgeon published in a vernacular tongue, his native French.

Prior to Vesalius, surgery remained distinct from medicine because it was not guided by theory, most notably that attributed to Hippocrates (460-377 B.C.). Hippocrates emphasized preventative medicine. Examining a patient, a Hippocratic physician, unlike a surgeon, was passive. He examined the bodily fluids, particularly the effluent, urine, but did not seek to intervene. Hippocrates's regimen of health emphasized four qualities - hot, dry, moist, cold - with balance as the key. The qualities of the external environment related to the qualities of the human interior through the intake of food, water, and of course, air.

Upon his arrival in the Caribbean, Columbus described green islands blessed with "mildness of cold and heat, in abundance of good healthful water." The foundation for his remark can be found in the Hippocratic corpus, and here he has mentioned two of the all important qualities, cold and heat. Outside the body, these qualities in their extremes (too moist, too dry, etc.) could create unhealthful habitats for human populations; hence, the importance Columbus placed on mildness. Controlling the climatic qualities, of course, was impossible, but individuals could evaluate regional qualities in their choice of places to live. Columbus wrote assuringly that "under the sun there can be no better lands." This optimism was repeated in the title of the first English translation of work devoted to American materia medica, Joyfull Newes Out of the Newe Found World (1577).

Not all the news from abroad was good, and the new times brought new diseases. Scurvy, a new malady of long ocean voyages, sent panels of helpless doctors to puzzle over their books. The mysterious English sweat drove soldiers to anxiety attacks, delirium, and untimely death. Another new scourge, typhus, killed 17,000 troops of Ferdinand and Isabella during the siege of Granada (1488-90). Disease suggested larger disorders, but there was no general understanding of disease vectors. During epidemics, local governments used their authority to protect citizens by imposing quarantines. Many late medieval European cities could boast other public health measures - hospitals and bath-houses with hot water. By the end of the 15th century, however, fears of another new disease, syphillis, ended public bathing, and many Europeans went about unwashed. Their hygiene did not improve in the New World, and untrammeled, typhus and other introduced diseases, especially African malignant tertiary malaria, devastated native populations. Columbus had reported healthy peoples, who endured hot sun and cold winters "with the help of meats which they eat with many and extremely hot spices." The fact that their native diet seemed to Columbus to conform to European medical theory offered no protection. After only one decade of European contact, the Taino were reduced from a population of a quarter million to 14,000.

The basis for Columbus's remarks about nutrition was again Galen. Galenists regarded the liver as central to the breakdown of foods and the manufacture of blood. In the Hippocratic sense, nutrition was probably the most important link between the body's interior condition and the external environment. The intake of food and water was one way in which the body internalized usable parts of the outside world and provided materials for growth. The foods of a balanced diet maintained the proper ratio between external substances with certain qualities and the bodily fluids or humors made from them.

In the 15th century, health implied a balance of four humors - phlegm, blood, black bile, and yellow bile - which Islamic and Christian literature associated with four organs - the brain, heart, spleen, and liver. Of Greek origin, humoral theory acquired a lot of baggage after the four humors were matched up with the four elements and four qualities. By the Middle Ages, these pairs were placed within the flux of the four seasons - spring, summer, fall, and winter. The body's humoral balance could be disrupted by improper regimen (overeating, thirst, sloth) or by the external environment.

Excess humors caused moods and minor ailments. For example, too much black bile led to melancholia, the subject of Albrecht Durer's famous engraving of 1514. The English words phlegmatic, sanguine, bilious and choleric also take their meanings from superfluous humors.

The humor most sensitive to the meat diet of the 15th century was blood. Blood was viewed as part of two separate systems of arteries and veins, and there were several ways to rid a body of too much blood. Induced fevers burned off excessive blood. Cut blood vessels drained off extra blood, and applied leeches sucked away unwanted blood. Since the humors affected personality, bloodletting was as highly individual as temperament. There were, all the same, standard ways to bleed. Charts showed the best points on the body's surface to bleed, and printed works such as the popular Regimen sanitatis salernitanum (1484) told the best times to bleed - the months of September, April and May.

Nature Study

The 15th century understanding of nature should not be confused with an interest in wilderness. Nature encompassed the relationship of the body, the microcosm, to the universe, the macrocosm. Nature was related to the state of being, and the study of nature included astrology, alchemy, and magic, as well as natural history.

In a spherical world, the enclosed garden was a favorite emblem for the study of nature. Wild open places were not enjoyed as parks. Europeans did not value wilderness. Each year they destroyed more and more forests. Even in warm seasons, the kilns of the booming 15th-century ceramics industry required constant fuel. By 1500, Spain had to import firewood. Viewing the heavily wooded mountainsides of the present-day Dominican Republic, Columbus could not contain himself: "the trees were so dense that it was marvelous, and there were such varieties of trees, unknown to anyone, as was astonishing." He and his crew were admiring the abundance of the trees, not the wildness of the habitat.

Columbus referred to Pliny's work to identify trees, specifically rubber trees. Writing for his royal patrons, he made frequent remarks about plants and animals, ranging from the poisonous manchineel tree to the harmless ground iguana and brightly plumed parrots. Looking at nature was part of the Renaissance within the visual arts, and one product of humanism, better Aristotelian texts, gave additional incentive to this endeavor. Eight editions of Aristotle's works treating natural history were in print by the year of Columbus's third voyage. For herbalists, the edition printed between 1495 and 1498 included the botanical work of Aristotle's pupil and heir to his library, Theophrastus (380-287 B.C.). One does not have to look far to find their influence.

Aristotle's attention to biological details stimulated the decorative, but surprisingly accurate, use of natural history in illuminated manuscripts still being produced for royalty. For example, the unidentified artists of a lavish book of religious lessons made for Isabella of Castile, and now owned by Harvard University, preferred the emblems of nature, to even those of his patron. The bright border of birds, berries and wildflowers on one page almost hides the queen's coat of arms.

New editions and vernacular translations fostered comparisons and closer examinations of local species and the works supposed to describe them. A second plant authority was Pliny's contemporary Dioscurides (active A.D. 50). His Materia Medica described 500 healing plants. These species were Mediterranean in origin, but traveling ecclesiastics and commercial drug traffic made many available throughout northern Europe. This commerce may explain the fact that early printed editions of Materia Medica were not illustrated. All the same, although local flora did not match Dioscurides's descriptions, those involved with the task of identifying plants hesitated to break with the past. In Germany, Leonard Fuchs (1501-1566) hired artists to draw plants from nature for his Historia Stirpium published in Basel in 1541. The elegant plates are accurate, but much of the text is a rehash of Dioscurides.

The first natural history of the West Indies was written by Gonzalo Fernandez de Oviedo (1478-1557) and published in Toledo in 1526. Using Pliny as his guide, Oviedo provided a chatty account, filled with colorful details of a happy traveler. Oviedo knew Columbus's sons and some of the crew members of the third voyage, but he did not travel to the Caribbean until 1513, after which time he made many trips. In this regard, he was unusual among Renaissance naturalists.

Plants described by Greek, Roman, and Islamic authors provided men and women of the Renaissance with tonics and medicines. To these were added, in an exchange personally encouraged by Oviedo, plants from the Caribbean, Mexico, and later, Peru. The value of plants for health gave rise to a variety of European occupations. Among the herb gathers, who collected the plants, rhizomatists hunted and dug out underground plant parts. Physicians prescribed medicines, apothecaries dispensed them, and herbalists wrote about them. By the 16th century, druggists, who prepared potions from the plants, had adapted alchemical apparatus for distillation and fermentation.

In a world where everything had its proper place, local plants were thought to hold the cures for local diseases. Travelers, fearing strange diseases, were attentive to the flora and plant lore of new places. Looking at nature was part of a program of health. Columbus's diary entries show his keen interest in the vegetation around him. "I have found rhubarb and cinnamon, and I shall find a thousand other things of value." His identifications were erroneous, but within a century, the gardens of the Old World were growing Caribbean vegetables - maize, chile peppers, prickly pear cactus, pumpkins, and beans. Some were prized for their beauty; others, as Columbus hoped, for their usefulness.

There was another side to nature, the hermetic or occult, which captured the Renaissance imagination. "Magic is the sum of natural wisdom, and the practical part of natural science," claimed Pico della Mirandola (1463-1494). Obscure to the senses, magic, more than Aristotelian science, seemed to connect human life with the rest of the cosmos. The work central to this revival of magic was attributed to the apocryphal Egyptian Hermes Trismegisthus and underwent sixteen printed editions between 1471 and 1500. Hermetic lore revitalized astrology and imbued natural things such as birthstones with sympathetic virtue.

Interest in magic bolstered fanciful description. One bestiary or animal book popular at the time of Columbus tells of monkeys that are "merry at the time of the new moon" and salamanders that live in fire. In 1491, the newly printed Book of Secrets said that emeralds improve memory and frog meat silences dogs. These "secrets of nature" seemed to come true after sailors returned from the Caribbean with tales of "barkless" dogs and looted emeralds the size of a man's fist.

Interest in magic grew, rather than declining during the 16th century. In northern Europe, Paracelsus (1493-1541), like many of his contemporaries, shared a sense of impending doom. A religious man, he foresaw the destruction of present order before the dawning of a new golden age. Paracelsus viewed the individual as a microcosm of the larger world. Magic opened the way for human interaction with the macrocosm. His idea of magic was useful and included the manual arts and experimental science, with which it and astronomy shared a predictive quality. Paracelsus boldly declared that the four Aristotelian elements - earth, air, fire, and water - were bunk. In their place, he proposed three chemical elements - sulphur, mercury, and salt. Paracelsus's rejection of scholastic science accompanied his devotion to alchemy. For serious students, alchemy went beyond metallic transformation, a way to turn base metals into gold. Alchemy promised man-made chemical products as substitutes for herbal medicines. It was a form of redemption and according to its advocates, promised a new understanding of nature.

At a time when plus (+) and minus (-) signs were finding their way from shipping crates into arithmetic, Gerlamo Cardano (1501-1576) was studying probability: "the most fundamental principle of all in gambling is simply equal conditions." Here Cardano, an expert cardplayer, is discussing games of chance, but his statement could be applied to navigation or celestial motion in a closed universe.

According to Christian theology and the Aristotelian philosophy it sanctioned, the future was part of nature's purpose, and everything in nature had meaning. Seeking this meaning, scholars studied science and math, and they sought insight with magic. On the grandest scale, the positions of the stars were omens for the affairs of men, from bloodletting to the demise of kings. On the more modest scale of human frame, Cardano and other chiromancers used lines of hand and facial warts for divination. Cardano, Parcelsus, and probably Columbus, did not see a conflict between these two ways of knowing nature and the future.

Within four decades after the death of Columbus, the European understanding of nature profoundly changed. Travel, printing, military actions, humanism, and disease all played a role in the scientific revolutions of the late Renaissance. New approaches to nature and new methods led to different ideas about nature. Each of these changes in thought involved comparisons in the formulation of insight. Copernicus compared two planetary orders to get the best fit for numerical computations; similarly, Galileo (1564-1642) later compared two world systems (the Ptolemaic and Copernican) in the old form of a Platonic dialogue; Vesalius compared descriptions in Galen and Avicenna to tissues in dissected cadavers. Fuchs compared old texts with living plants. Paracelsus compared the microcosm with the macrocosm. Cardano compared cards. In the process, Greek, Roman, and Islamic authorities were reviewed; some were revised, others such as Avicenna were left behind.

How important were the voyages of Columbus to this new approach to the natural world? Some academic thinkers dismissed his discoveries as sailors' work; others minimized the importance of his little islands for world affairs. By contrast, the philosopher of the scientific revolution, Francis Bacon (1561-1626) chose Columbus's sailing through the Pillars of Hercules as a symbol for a new organon or tool of knowledge. Bacon recognized that Columbus was an experimenter who used the knowledge of his senses, as well as that obtained from books, to guide the development of his ideas.

A century ahead of Bacon's pitch for the advancement of knowledge, Columbus believed in the possibility of augmenting information about the natural world. As his four voyages to the Caribbean show, he acted on the belief that tradition could accommodate novelty. Like Vesalius and Copernicus, he sought a better fit between the abstract and the actual, a world model and, in his case, trade routes.

Not all of Bacon's contemporaries shared his high estimation of this exploratory or experimental approach to knowledge. Hear John Donne (1572-1631), the great sermon writer and poet of the Elizabethan era. His Nosce Teipsum questions the value of science and geographical exploration.

We seek to know the moving of each sphere,
And the strange cause of the ebbs and floods of Nile,
But of that clock within our breasts we bear
The subtle motions we forget the while.

We that acquaint ourselves with every zone
And pass both tropics, and behold the poles,
When we come home, are to ourselves unknown,
And unacquainted still with our own souls.

In his quest for personal redemption, Donne is comparing knowledge of the world to knowledge of self. Donne's language is dialectical, continuing the rhetorical tradition 15th century humanists had borrowed from ancient Rome. But gone are mental repose and satisfaction, the museum companions of the best classical art. Donne's intimacy is uncompromising. In his view, manifestation of the globe at large does not shed light on human action. In the most profound sense, science is not synonymous with knowledge of nature.

Although Columbus became disheartened before his death in 1492, he did not share Donne's skepticism. He undertook his second and third voyages believing that he had reached Asia. There was, however, another aspect of the explorer's attitudes toward his mission. Columbus hoped and prayed with the Spiritual Franciscans that geographical exploration would lead to global unity under Christendom. In 1501-1502, he wrote in his Book of Prophecies, "There will be peace and great tranquility upon the earth, such as has never yet existed, and there will never be any like it since this is the last, at the end of the ages." The history of the world, nature itself, would then be complete.