Eva Anglessy **21/10/2024**

Research Paper:

The Relationship of Science and Art in Britain's "Modern" History

The Orrery, ca 1766, by Joseph Wright of Derby (1734–1797), Derby Museum and Art Gallery[1]

[1] Public Domain: File:Wright of Derby, The Orrery.jpg - Wikipedia

Abstract

When C.P. Snow suggested in 1959 that intellectual life had become divided into two separate cultures—the sciences and the humanities—he was in fact reopening a debate which had already shaken up the academic world in the 1870s-80s, about the type of education necessary to foster "true culture". And in its introduction to the recent book *Histoire des Sciences—De l'Antiquité à nos jours*, Philippe de la Cotardière still argues that "science always struggles to be integrated into the cultural sphere on an equal footing with arts or literature."[2]

However, "natural philosophy," as science was called from antiquity to the 19th century, was not always looked down or as a threat by literary intellectuals, nor separated from the other fields of human knowledge and culture. Though sometimes criticized by some Romantic artists such as Blake, even ridiculed by 19th century cartoonists or writers, scientific theories, experiences and institutions were admired by many others, who recognized the growing place of science in their contemporary societies as a welcome addition to the human knowledge. Some scientists, like Humphry Davy and Erasmus Darwin, understood science as another creation of human imagination, like art and poetry, and their legacies embrace both science and literature: "and" instead of "either…or".

Adopting an inclusive approach, the purpose of this research paper is to demonstrate how science and arts (including literature) were intertwined in Britain's "modern" history, focusing on the period from the Scientific Revolution to the Industrial Revolution. From the artistic illustrations of the human body in Vasilius's publication *De humani corporis fabrica* (1543) to the use of contemporary scientific experiences in Mary Shelley's novel *Frankenstein* (1818), from the symbolic use of armillary spheres in Queen Elizabeth I's portraits to the realistic representations of scientific experiences in Joseph Wright of Derby's paintings, this research paper will show that art and science are both creative ways of understanding the world. Their approaches may be different, but they are complementary in our human society, and both are essential in our education systems.

Acknowledgements

For the chronological presentation of science evolution in this Research Paper, I am particularly indebted to William Bynum's and Yves Gingras's books, respectively *A Little History of Science* and *Histoire des sciences*, which aim at popularizing science for a wide public, especially young people.

[2] Philippe De La Cotardière, *Histoire des Sciences – De l'Antiquité à nos jours*, p. 9 (my own translation).

Contents

Introduction

In 1959, C.P. Snow launched a fierce debate in the academic world, when he suggested that intellectual life had become divided into two separate cultures—the sciences and the humanities. It echoed a previous controversy between Matthew Arnold and Thomas Huxley in the 1870s-80s, about the places of science, arts and literature in Britain's education policies. But what did they mean exactly? And how did they arrive to this conflictual view of sciences against humanities?

As soon as we try to describe how art and science evolved in human history, we first struggle with the definition of the following terms: what do we mean when speaking of art? Of science? Of engineering or technology? Of knowledge? The meanings of these notions depend on the period we consider, the language we speak, the approach chosen by historians…

For instance, the notion of "fine" art was not used before the 17th century, when painters started to be regarded as "artists" instead of artisans. In this research paper (RP), I used the word "art" in its present sense of "the conscious use of skill and creative imagination especially in the production of aesthetic objects, as well as the works so produced." [3]

Even though the word science already existed in Middle English—meaning "knowledge, the ability to know, learning, branch of knowledge"—it was not used in its modern sense before the 19th century and the term "scientist" was only coined in 1833, by analogy to "artist". Indeed, "natural philosophy" was the term used from antiquity until the early 19th century. Some science historians have limited the notion of "natural philosophy" to physics, while for others, it also encompassed botany, zoology, anthropology, and chemistry. Today, science is used in the inclusive meaning of "knowledge or a system of knowledge covering general truths, or the operation of general laws, especially as obtained and tested through scientific method,"[4] thus we speak of "natural science", as well as "social sciences", "computer science", etc.

Interestingly, the way society regards engineering and its links with science and art varies with the countries, as shown in their different languages: engineering was linked to industry in Britain earlier and stronger than in France, where its links with science and art remain more apparent. The English word "engineering" covers the two French notions of "*sciences de l'ingénieur"* and "*ingénierie*"; reciprocally the close French words "*oeuvre d'art*" (work of art) and "*ouvrage d'art*" (a structure in civil engineering) refer to different lexical fields in English.

Do we have to accept the academic hierarchy of the "pure" sciences above the applied ones or technology—as the "fine arts" are esteemed superior to the "decorative arts"—because of the notion of utility of the latter, even if it is the invention of the printing press in the 15th century that triggered a wider and faster diffusion of knowledge, thus sustaining the so-called "Scientific Revolution" in the following centuries? Human beings have always liked categorizing and creating hierarchies, either to order their world or to foster a sensation of power or exclusivity… In this RP, however, I chose to highlight important inventions which helped further the human knowledge, be they scientific or technical.

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[3] Definition from the Merriam-Webster dictionary: Art Definition & Meaning - Merriam-Webster

[4] Definition from the Merriam-Webster dictionary: Science Definition & Meaning - Merriam-Webster

Therefore, since antiquity the notions of art, science, and culture have changed, expanding and moving with human knowledge and societies. The various theories and historiographies linked to the evolution of these notions throughout history have become themselves the topics of separate academic fields, and it is not the purpose of this RP to study them. However, it is useful to underline from the start their complexity to explain why I chose a chronological and inclusive approach to explore the interrelations between science, art and literature—and the sustaining role of technology—in Britain's "modern" history.

We cannot understand the change of paradigms which happened in sciences between the 16th and 17th centuries if we do not have a basic understanding of the antic knowledge which was then questioned. Therefore, in the first part of this RP, I will explore some basic notions of science in antiquity, the reasons why scientific knowledge focused on astronomy, mathematics and living matter, and the transmission of this ancient knowledge through the Arabo-Muslim world to western medieval societies. I will briefly explain the development of medieval universities in Europe, how scholars and artists rediscovered classical works during the Renaissance and illustrate my text with relevant examples of inventions and works mixing art, science and engineering.

In the second part, I will summary the concept of Scientific Revolution and the debate between historians that this notion triggered. Then, focusing on the period between Nicholaus Copernicus's 1543 *De revolutionibus* and Isaac Newton's 1687 *Principia*, "when the foundations of modern science swept away the scientific heritage of the ancient and medieval worldviews,"[5] I will underline that philosophers such as Descartes and Bacon were also scientists, and that science and art mingled in the printed works of this Era. During the Enlightenment, science became institutionalized. Though some men of letters and artists admired and celebrated the works of men of science, others criticized and even satirized scientific institutions.

In the third part, I will show how science entered at the service of industry and capitalism during the Industrial Revolution, and triggered various responses among Romantic artists and writers, and their Victorian successors throughout the 19th century. I will then examine the "amicable conflict" between Matthew Arnold, champion of humanities, and Thomas Henry Huxley, champion of sciences, which started when defining the type of education necessary to foster true culture during the 1870s and 80s. This debate was reopened in 1959 by C.P. Snow's Rede lecture in Cambridge, entitled "The Two Cultures".

To conclude, I will give my personal response about C. P. Snow's statement and my perception of the relationships between science, literature, and arts in culture. As sciences and art movements have become much more complex and diversified since the beginning of the 20th century, I ended my study at the end of the 19th century. However, science, arts and literature have remained strongly intertwined in Western societies since then, through what is called the "second Industrial Revolution," the first then the second world wars, up to the "Information Age" (or the third Industrial Revolution). In my conclusion, I will thus illustrate some of my arguments with recent examples.

[5] R. Fleck, 'The Scientific Revolution in Art', p. 139.

Part 1: From antiquity to the Renaissance

In this research paper (RP), my narrative of ancient sciences begins in Greece, where the main sources of modern sciences developed between 500 BC and 300 AC, even if some previous scientific knowledge can be traced back to earlier human societies that settled in river valleys across India, China and the Middle East. Indeed, the knowledge gathered by these ancient civilizations in writing, counting, and astronomy answered their needs in astrology, religion, agriculture and calendar. For example, the Babylonians said that there should be sixty seconds in a minute and sixty minutes in an hour, as well as 360 degrees in a circle and seven days in the week. They defined the first Zodiac, the basis of astrology, which is the study of the influence of the stars upon us. Egyptian astronomy was similar to the Babylonians', and for them, the calendar was very important to define the best time to plant, or when to expect the Nile to flood, but also to plan religious festivals. They added an extra five days at the end of their 360-day year, to keep the seasons from slipping. From India came numbers and a love of mathematics, and from China, paper, gunpowder, and the compass, an indispensable instrument for navigation.[6] However, ancient astronomy was more temporal than spatial, and more based on arithmetic than on geometry and there are very few attested indications of continuity between the cumulated knowledge of Babylonians, Egyptians, Chinese and Indians, and that which were built by the Greeks during the millennium between 500 BC and 500 AC. Only some Babylonian arithmetic methods and data seem to have partially been transmitted to Greek astronomers, but the latter's astronomy was very different and based on geometrical models. Not only is there a historical hiatus but also an epistemological one between Greek sciences and the ones of previous civilizations.[7]

The Ancient Greek civilization brought about political, philosophical, literary, artistic[8], and scientific achievements that formed a legacy with unparalleled influence. In the fifth century BC, people who thought and wrote in Greek dominated a growing part of the eastern Mediterranean. They had already written down *The Iliad* and *The Odyssey*, the epic poems attributed to Homer. Indeed, not only were the Greeks great shipbuilders and traders, they also were great thinkers. According to Yves Gingras, the Greek way of questioning nature was specific to their civilization and certainly built the foundations of later developments in Arabo-Islamic and western worlds: "the distinctive Greek conception of knowledge, be it in medicine, mathematics or astronomy, aims to set up general demonstrations of phenomena based on basic premises, and proposes a geometric vision of a *cosmos* forming an organized whole in a three-dimensional spherical space".[9] However, like the scribes of the first civilizations, we have very few information about the first Greek thinkers of the sixth and fifth centuries BC.

In medicine, for example, the Hippocratic Corpus was actually written by Hippocrates (460-370) and many other doctors over a long period of time. Their treatises laid the foundations of Western medicine, and its three broad principles have guided medical practice for centuries.

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[6] William Bynum, *A little History of Sciences*, pp. 3-6

[7] Yves Gingras, *Histoire des Sciences*, pp. 32-33 (my translation).

[8] For artistic examples and more information, see: https://www.metmuseum.org/toah/hd/tacg/hd_tacg.htm

[9] Yves Gingras, *Histoire des Sciences* pp. 34-35

The first still underpins our own medicine and medical science: the firm belief that people fall ill because of 'natural' causes that have rational explanations, not because they have offended the gods or because someone cast a spell on them.
The second principle was that four 'humours' in the human body—phlegm, yellow bile, blood and black bile—play essential roles in its health, and that disease occurs when they get out of balance. Each of the humours had its properties: blood is hot and moist; phlegm, cold and moist; yellow bile, hot and dry; black bile, cold and dry. Galen (129-c. 210) who developed Hippocratic ideas about 600 years later, also gave these same characteristics of hot, cold, moist and dry to the food we eat, or drugs we might take. The cure for all illness was to restore whatever balance of humour was best for each patient, thus Hippocratic medicine was based on careful observation of diseases and the course they took. Doctors wrote down short summaries of their experiences, called 'aphorism'. *Aphorisms* was one of the Hippocratic works most widely used by later doctors.
The third important Hippocratic principle was to believe in the healing power of nature: the doctor's job was therefore to assist nature in the natural healing process.
Beside their many works on medicine and surgery, hygiene and epidemics, the Hippocratics left us the Oath, still a source of inspiration to doctors today.[10]

Documents written before the fifth century BC have generally be transmitted to us through the form of fragments referred to in later texts, like the work of Thales (c. 625-c. 545). A merchant, astronomer and mathematician of Miletus, Thales thought that water was the chief element, and he wanted to explain things in natural, rather than supernatural, terms, such as the fertilization of the land by the flooding of the Nile (while the Egyptians thought that the Nile flooded because of the gods).

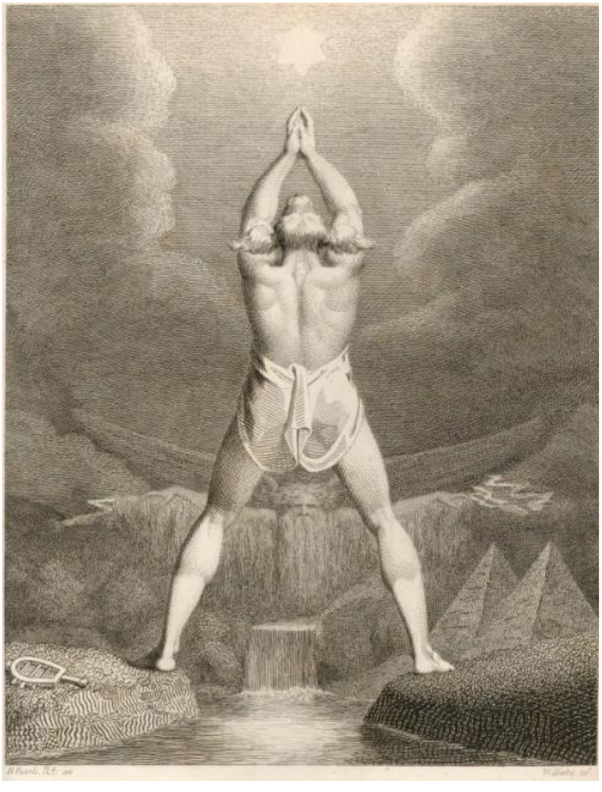

Fig. 1: Fertilization of Egypt, (1791), by Henry Fuseli (1741 - 1825) [11]

[10] William Bynum, *A little History of Sciences*, pp. 19-23
[11] Fertilization of Egypt | Works of Art | RA Collection | Royal Academy of Arts

Like Thales, other thinkers from Miletus believed in a single, universal, element but monism could not explain matter changes. Empedocles (c. 500-430), from Sicily, solved this problem with the idea of matter being composed of four elements—air, earth, fire and water—and that matter changes could be explained by modifications in the proportions of these four elements. Their names had then a wide meaning, referring to the fluidity, volatility and solidity of different materials. Though criticized, this conception remained a reference until the 18th century.

The theory of the four elements often combined with the four fundamental qualities (hot, cold, moist and dry), to which the alchemist tradition added three "principles" (sulfur, mercury and salt). The medical theory was also based on four humours, which were also supposed to define the fundamental human characters. The elements could also transform one another by modifying their qualities, principles or geometric composition, in accordance with figure 2.

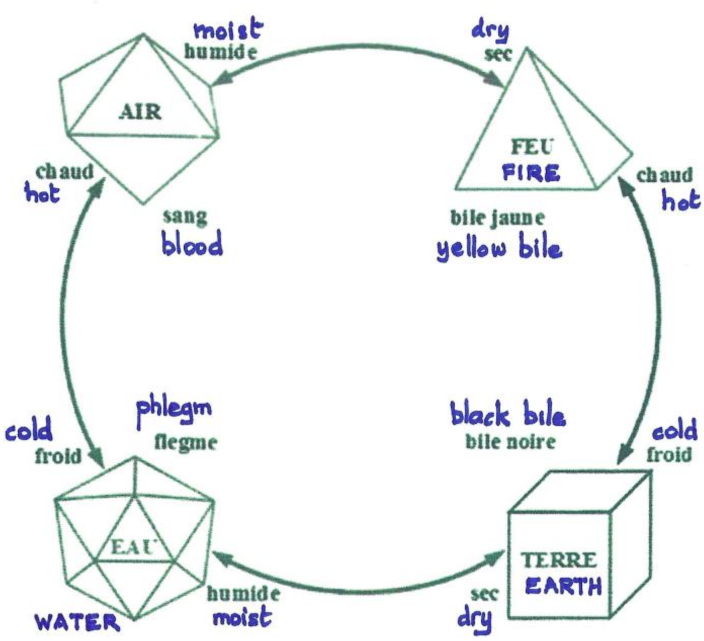

Fig. 2: Explanation of the transformation of elements through recombining triangles and modifying qualities[12]

This conception gave a theoretical base to the alchemists' attempts to transform lead into gold. The four qualities were also linked to the planets, thus giving astrology a kind of rational justification of the planets' influence on human actions (see p. 12).

Plato's *Timaeus* explains the transformation of elements through the rearrangements of triangles which form the five regular solids[13]. Plato combined each of the four elements to one of these solids and identify the fifth one (the dodecahedron, the closest to the sphere) to the universe, regarded as a living organism. This idea of geometric and harmonic foundations of the universe, thus musical and obeying strict proportions, was still vivacious in the 17th century, and inspired Kepler in his book *Mysterium Cosmographicum*, published in 1596, which suggests regular solids fitting together to explain the relative distances between planets (see Fig. 22 p. 24).[14]

[12] Yves Gingras, *Histoire des Sciences*, p. 43 (my translation)
[13] See Platonic solid - Wikipedia
[14] Yves Gingras, *Histoire des Sciences* pp. 42-43 (my translation).

However, another group of philosophers, in Greece and later in Rome, did not accept this four-element scheme. Leucippus (460-370) suggested that matter is made up of tiny particles called atoms, of different forms and in indefinite quantity. This theory was later developed by his contemporary philosopher, Democritus, and transmitted by the Latin poet Lucretius (94-54) in his long scientific poem *De rerum natura* (*On the Nature of Things*). In this poem he described the heavens, the earth and everything on the earth, including the evolution of human societies, in terms of atomism. This work, rediscovered at the beginning of the 15th century, played an important role in the renaissance of atomism at the end of the 16th and beginning of the 17th centuries.[15]

Though the Babylonians had been quite good in geometry, Euclid (c. 330-c. 260) was the first to bring together the basic assumptions, rules and procedures in his great book, *Elements of Geometry*, followed by *Conics* written by Apollonius of Perga (c. 240-c. 190), a great mathematician known as "The Great Geometer," and the works of Archimedes (287-212), the most famous mathematician and inventor in ancient Greece. He is especially important for his discovery of the relation between the surface and volume of a sphere and its circumscribing cylinder. He is known for his formulation of a hydrostatic principle (known as Archimedes' principle) and a device for raising water, still used, known as the Archimedes screw.[16]
Greek contributions in geometry defined the general framework of research in mathematics for the following centuries. Some of these works, translated in several languages throughout history, remained the reference in mathematics until the 19th century.

In astronomy too, Greek scholars developed a specific theory based on the idea of spherical earth and heavens. Their geometrical model used concentric spheres around a fixed Earth. The combined rotative movements of these spheres were intended to reproduce the trajectories observed on the celestial sphere. A first model of concentric spheres, defining planets order—as seen from the Earth (the Moon, Mercury, Venus, the Sun, Mars, Jupiter and Saturn)—was widely spread through Plato's *Timaeus* (c. 360). Being too simple, this model was then modified by several astronomers and mathematicians to better describe the observed phenomena. Eratosthenes (c. 284-c. 192), librarian of the famous museum and library in Alexandria (see p. 9), used geometry to measure the circumference of the earth, and already thought that the earth was round.
Their previous works were used and developed in Alexandria by Claudius Ptolemy (100-168), who, like many scientists of the ancient world, had very wide interests: mathematics, astronomy, astrology, geography, and music. His main work, *Mathematical Treatise*, is best known in the Latin world under the title given to it by the Arabs, *Almagest*. In this book, Ptolemy brought together and extended the observations of his predecessors, including charts of the stars, calculations of the movements of the planets, moon, sun and stars, and the structure of the universe—with the earth at the centre of everything. Ptolemy's book was essential reading for astronomers in the Islamic lands. While mathematical contributions began to dry out in the Greek world after the fourth century AD—the Romans contributing very few to the development of astronomy—comments, criticisms and alternative geometric models to correct the weaknesses of Ptolemy's work spread in the Arabic world. The contributions of two Arabic astronomers, Nasir Al-Din Al-Tusi (1201-1274)

[15] See Stephen Greenblatt's book about this subject, intitled *The Swerve* (2011).
[16] Source: Archimedes | Facts & Biography | Britannica

during the 13th century, and Ibn al-Shatir (1304-1375) during the 14th century, were later developed by Nicholaus Copernic (1473-1543), and this fact suggests a continuity in the transmission of knowledge in astronomy throughout the centuries, though we do not know exactly how it happened. Translated into Arabic in the ninth century AD, Ptolemy's work was translated again into Latin, then studied, criticized and amended in Europe until the 17th century.[17]

Aristotle's synthesis

Aristotle (384–322 BC) epitomizes the Ancient Greek philosopher and polymath. His writings cover a broad range of subjects spanning the natural sciences, philosophy, linguistics, economics, politics, psychology, and the arts. He spent his whole life learning—spending twenty years at Plato's Academy—and teaching. He founded his own school, the Lyceum, and surrounded himself with disciples interested in empirical studies, based on observation, especially in biology. He also tutored Alexander the Great, in Macedonia.
Contradicting the mixing of mathematics (which deals with form and relations) with physics (which deals with substance/matter), Aristotle criticizes his master Plato's theory and explains the changes of matter through the qualities associated with the four elements (Fig. 2, p. 5). He admits, though, that there are intermediate sciences between physics and mathematics, such as optics, which uses geometry to describe light rays.
Aristotle conceived a whole research programme covering the entire human knowledge. Regarding the diversity of the living world, Aristotle proposed a classification of living beings, *scala natura*, or 'scale of nature', like a ladder upon which all living things could be arranged, beginning with simple plants and working upwards, human beings sitting at the top. His train of thoughts drove him to distinguish matter and form, the latter having a central importance to explain the diversity of living beings, as well as their embryonic developments, described in *Generation of Animals*, one of Aristotle's major works. Thus, species (of plants or animals) are distinguished by their forms, because matter (the four elements) is the same for all. His work will usher a botanical tradition whose main aim was to serve medicine. When Plato and the Hippocratics had located psychological functions in the brain, Aristotle believed the heart was the centre of emotion and what we would call mental life. Though wrong, Aristotle's theory attributed the functions of living beings to the activities of a 'soul', which had various faculties. In human beings, the six main faculties of the soul were nutrition and reproduction, sensation, desire, movement, imagination, and reason.

In cosmology, Aristotle's treaties *Physics* and *On the Heavens* dominated scholarship until the 17th century. Aristotle divided the universe—unique, finished and eternal—in two heterogeneous spaces: from the moon downwards, change is always happening because the world is composed of the four elements, as well as decay and corruption. But above the moon, where the heavenly bodies move forever in perfect circular motion, things are made of a fifth, unchanging element, the *quintessence*. The sun, moon and stars have been moving for eternity around the earth, which floats at the centre of it all (Fig. 3, p. 8).

[17] William Bynum, *A little History of Sciences*, pp. 17-18 and Yves Gingras, *Histoire des Sciences*, pp. 35-40

Fig. 3: Description and distinction of celestial orbs, by Oronce Fine, *De Mundi Sphera* (1555) [18]

This conception would only be abandoned in the 17th century, with the union of heavens and earth in a single, homogeneous, and isotropic space.
But what caused all this movement around the earth in the first place? Scientists always want to know what happens and why, and Aristotle was very concerned by *cause*. He developed a theory of explanation, defining four types of causes, called material, formal, efficient and final causes. Explaining fully a phenomenon would require the identification of each of these causes. Mostly, scientists deal with what Aristotle called efficient causes, but final causes raise a different set of issues, which are rather linked to religion or philosophy. Looking at the universe as a whole, Aristotle argued that there must be some final cause that started off the whole process of movement, and later, many religions identified this force with their God.
This was one of the reasons why Aristotle continued to be celebrated as such a powerful thinker: he created a worldview that dominated science for almost 2,000 years. [19]

For two millenniums (from 500 BC to c.1600), people who devoted a part of their time to question the constitution of the world and the causes of the various changes occurring in nature only represented a tiny minority of individuals. In ancient Greece, scholarship took place in the great cities, sources of the intellectual development of civilizations: Athens (fifth century BC), where Plato, Aristotle, Epicureans, and Stoics founded schools of philosophical thought; then Alexandria (from the fourth century BC to the fourth century AC) where was founded the famous museum and library at the end of the third century BC, under the dynasty of the Ptolemies.

[18] Oronce Fine, De mundi sphaera 1555 – Museo Astronomico di Brera (inaf.it)
[19] William Bynum, *A little History of Sciences*, pp. 24-29 and Yves Gingras, *Histoire des Sciences*, pp. 43-47

It was the first institution especially devoted to the development and safekeeping of the knowledge. Many scholars spent a part of their lives there, astronomers, doctors specialized in anatomy or physiology, and mathematicians. A strong tradition of engineering also developed in Alexandria, ushered in by Ctesibius (285–222 BC), who wrote treatises on water clocks, pumps, and levers.

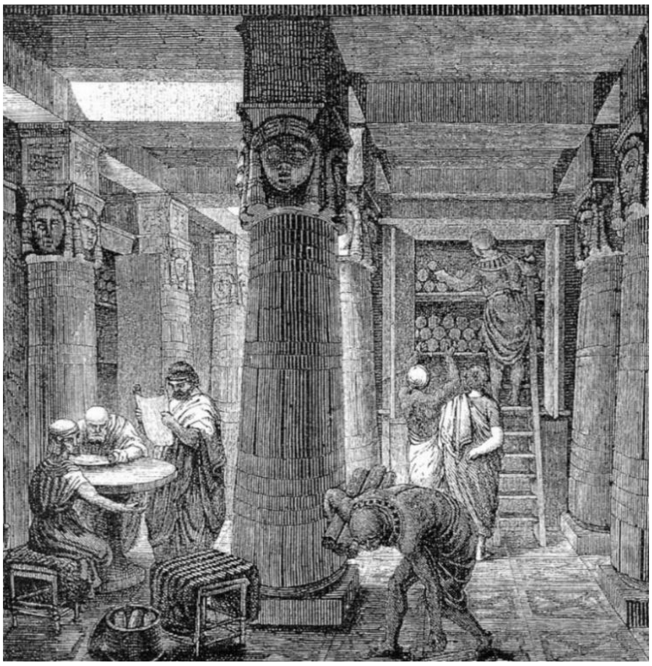

Fig. 4: Imaginative 19th century engraving of the ancient Library of Alexandria[20]

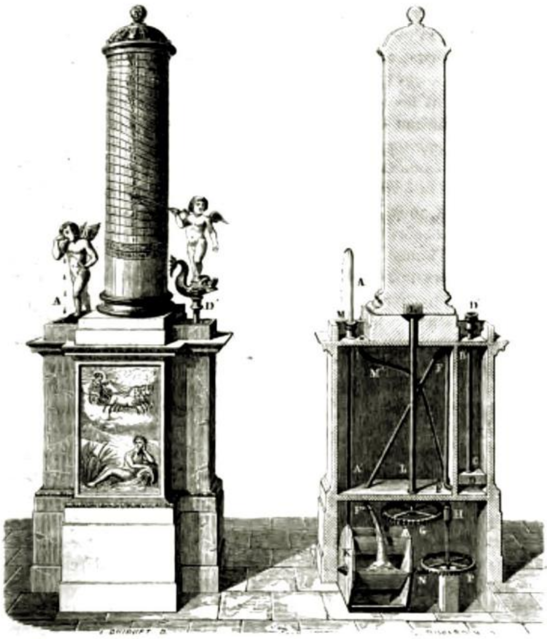

Fig. 5: Ctesibius' water clock, as visualized by the 17th-century French architect Claude Perrault[21]

The Roman Empire (27 BC- 476 AD) was distinguished not only for its outstanding army and paved roads, but also for its accomplishments in intellectual endeavours (Roman law and literature, from Cicero's speeches to the poetry of Virgil) and engineering feats: Roman city planners achieved unprecedented standards of hygiene with their plumbing, sewage disposal, dams, and aqueducts (Fig. 6). Roman architecture, though often imitative of Greek styles, was also innovative, like the dome of the Pantheon (Fig. 7). The famous Roman baths (Fig. 8), with their extraordinary system of water heating and lavish decoration, were built to stir the senses as well as to cleanse the body. [22]

Fig. 6: An example of a Roman aqueduct: Pont du Gard, in France [23]

[20] Public Domain, https://commons.wikimedia.org/w/index.php?curid=2307486
[21] Public Domain, https://commons.wikimedia.org/w/index.php?curid=18924767
[22] Source: Roman Empire - Expansion, Decline, Legacy | Britannica
[23] Public Domain: File:Pont du Gard (30).jpg - Wikimedia Commons

Fig. 7: *Interior of the Pantheon, Rome*, c. 1734 [24]

Fig 8: The Roman Bath, Bath (GB) [25]

The epitome of the Roman architects—combining landscape architects, civil engineers, military engineers, structural engineers, surveyors, artists, and craftsmen—is Vitruvius, who is mostly known for his work *De architectura* and lived during the first century BC. In his book, Vitruvius argues that a structure must exhibit the three qualities of stability, utility, and beauty. For him, architecture is an imitation of nature. As birds and bees built their nests, so humans constructed housing from natural materials, that gave them shelter against the elements. When perfecting this art of building, the Greeks invented the architectural orders: Doric, Ionic and Corinthian. It gave them a sense of proportion, culminating in understanding the proportions of the greatest work of art: the human body, that Vitruvius tried to inscribe in the circle and the square (the fundamental geometric patterns of the cosmic order, respective symbols of the divine and the earthly). [26] This idea was later developed by Renaissance artists such as Leonardo da Vinci (see p. 17).

The Roman Empire conquered most of the island of Britain, which was inhabited by the Celtic Britons, and became the Roman province of Britannia. Starting in 43 AD, under Emperor Claudius, the conquest was largely completed in most of England and Wales by 87 AD, when the Stanegate was established. During their occupation, which ended around the fifth century, the Romans built an extensive network of roads—which continued to be used in later centuries—forts, towns, villas, and water supply, sanitation and wastewater systems. For centuries after the Romans left Britain, fresh waves of Anglo-Saxon and Viking invaders and settlers came in, destroying Roman architectural legacy and bringing about new ways of life. Britain broke up into small kingdoms led by warlords. The period called ‘Dark Age’ by historians, though, saw new technological innovations, such as new

[24] Painting by G. P. Panini (1691 – 1765) Public Domain: Interior of the Pantheon, Rome (nga.gov)
[25] Source: Visiting The Roman Baths In Bath England - The Geographical Cure
[26] Source: Vitruvius - Wikipedia

ways of growing crops and of ploughing the land. Building churches and cathedrals encouraged craftsmen and architects to experiment with new styles and find better way of spreading the heavy weight of stone and timber. Architectural innovations, such as flying buttresses, were essential to creating the Gothic style (Fig. 9), but it was the new, intentional use of light that truly set Gothic architecture apart from its heavier and darker Romanesque predecessors.

Fig. 9: Detail of *Saint Barbara* (1437), by Jan Van Eyck, showing the building of a late Gothic church tower [27]

After the fall of the Roman Empire and the many conquering wars on mainland Europe too, scholarship moved from the Greco-Roman world to the Islamic world and its big intellectual centres, such as Baghdad, Damascus, Cairo, and Cordoba. The learning and wisdom contained in Greek and Latin manuscripts were translated into Middle Eastern languages, commented and developed between the 8th and 14th centuries, a period during which the domination of Arabic scholars is uncontested: for two dozen of European scholars during this period, historians count four times more scholars in the Arabo-Islamic world. Medicine, more than any other Islamic science, had the greatest impact on European thinking. Astronomy played a major role in the Islamic religion as well as in astrology and was sponsored by califs and vizirs. This link between astronomy and princes' sponsorship would continue in 17th-century Europe: astronomers and astrologers, whose disciplines remained inseparable before the middle of the 17th-century, were more numerous than mathematicians, for example, whose knowledge was less directly useful to rulers.
However, even under the protection of higher authorities, scientific activities remained marginal in human societies until the 12th century.[28]

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[27] Public Domain: [File:Jan van Eyck 011.jpg - Wikimedia Commons]

[28] William Bynum, *A little History of Sciences*, pp. 35-40 and Yves Gingras, *Histoire des Sciences*, pp. 47-56

The emergence of universities.

From the 12th century onwards, Christian Europe's vitality brought about by the growth of towns, the creation of universities and rediscovery of Aristotle's and Galen's works—as well as those of the great Islamic scholars who commented and criticized them—allowed thinking about science to flourish again. European scholars benefitted from an important movement of translation, very active in South Italy and Spain (Toledo and Cordoba) from the beginning of the 12th century. This activity made those texts available to the Christian world, just when the teaching of philosophy in the art faculties in universities was beginning to grow. Indeed, after the foundation of the first universities in Bologna, Paris and Oxford at the beginning of the 12th century, the needs of city-states furthered the creation of several universities in Europe, which knew an important economic growth until the Great Plague of 1348. Only a dozen in 1300, the number of universities soared to sixty in 1500. Supposed to cover the whole of human knowledge, universities usually had four faculties: Theology (the 'queen of sciences' according to Aquinas), Law, Medicine and Arts.
St Thomas Aquinas (c. 1225-74) was the greatest medieval theologian. He reinterpreted Aristotle's cosmology to make it compatible with the Christian doctrine of the Creation.
The medical faculties initially relied mostly on Galen and Avicenna, and medical students also studied astrology, because of the widespread belief in the power of the stars to affect humans, for better or for worse. This belief was still alluded to in Shakespeare's early 17th-century play *King Lear* (I, 2):

> GLOUCESTER.
> These late eclipses in the sun and moon portend no good to us: though the wisdom of Nature can reason it thus and thus, yet nature finds itself scourged by the sequent effects. Love cools, friendship falls off, brothers divide: in cities, mutinies; in countries, discord; in palaces, treason; and the bond cracked 'twixt son and father. (…) [*Exit.*]
> EDMUND.
> This is the excellent foppery of the world, that, when we are sick in fortune, often the surfeits of our own behaviour, we make guilty of our disasters the sun, the moon, and the stars; as if we were villains on necessity; fools by heavenly compulsion; knaves, thieves, and treachers by spherical predominance; drunkards, liars, and adulterers by an enforced obedience of planetary influence; and all that we are evil in, by a divine thrusting on. An admirable evasion of whoremaster man, to lay his goatish disposition to the charge of a star. My father compounded with my mother under the dragon's tail, and my nativity was under Ursa Major, so that it follows I am rough and lecherous. Fut! I should have been that I am, had the maidenliest star in the firmament twinkled on my bastardizing.

The seven 'Liberal Arts', codified in late Roman antiquity, were the subjects of secular education during the Middle Ages and the Renaissance (see Appendix 1). They were divided into the trivium—Grammar, Logic and Rhetoric—and the quadrivium—Geometry, Arithmetic, Astronomy and Music. The notion of "fine arts" (painting, sculpture) did not exist in the medieval world. It was the price of an object which defined its worth. A painter was then regarded as an *artisan*, less paid than a silversmith, for instance, until the Renaissance (see p. 17).
Aristotle's works on nature (physics, cosmology, biology) were studied, commented and criticized in all the faculties (Fig. 10). The dialectical method of teaching stimulated thinking on many problems regarded as solved by Aristotle's supporters. Many debates on the universe infinity, the existence of

void and the movement of the earth, for instance, took place in the European academic world, taking into account Christian theology and the premise of the infinite power of God.

Fig. 10: *Aristotle lectures to students* (c. 1350s) by Laurentius de Voltolina [29]

After the fall of Constantinople to the Ottoman Empire (1453), many eastern scholars fled to Italy. They brought books and manuscripts of Classical Greek wisdom and knowledge, which helped foster Renaissance ideas and values throughout Europe, as well as Islamic scholars' scientific advances. Their circulation was furthered by the invention of the printing press. Indeed, in about 1450, when books in Europe were rare, expensive and written by hand, Johannes Gutenberg (c. 1398-1468), a goldsmith in the German city of Mainz, set up the first European printing press. He used movable type, a method invented by the Chinese over 600 years earlier. Soon printing became quick and reasonably cheap. The result was an explosion of printing books, which helped the already growing number of people who could read—from scholars and royal ministers to tradespeople and craftsmen. Not only the Bible but also some fundamental scientific texts were then translated in vernacular languages, such as Euclid's *Elements*, which was published in French (1557) and in English (1570).

Moreover, at the end of the 15th century, maritime exploration allowed the discovery of geography and an unknown inhabited continent, with new flora and fauna (see Fig. 11); new instruments allowed more precise natural observations, as well as the invention of the telescope to observe the heavens; all these innovations contributed to a radical challenge of the Ancients.

[29] Public Domain: https://commons.wikimedia.org/w/index.php?curid=151733618

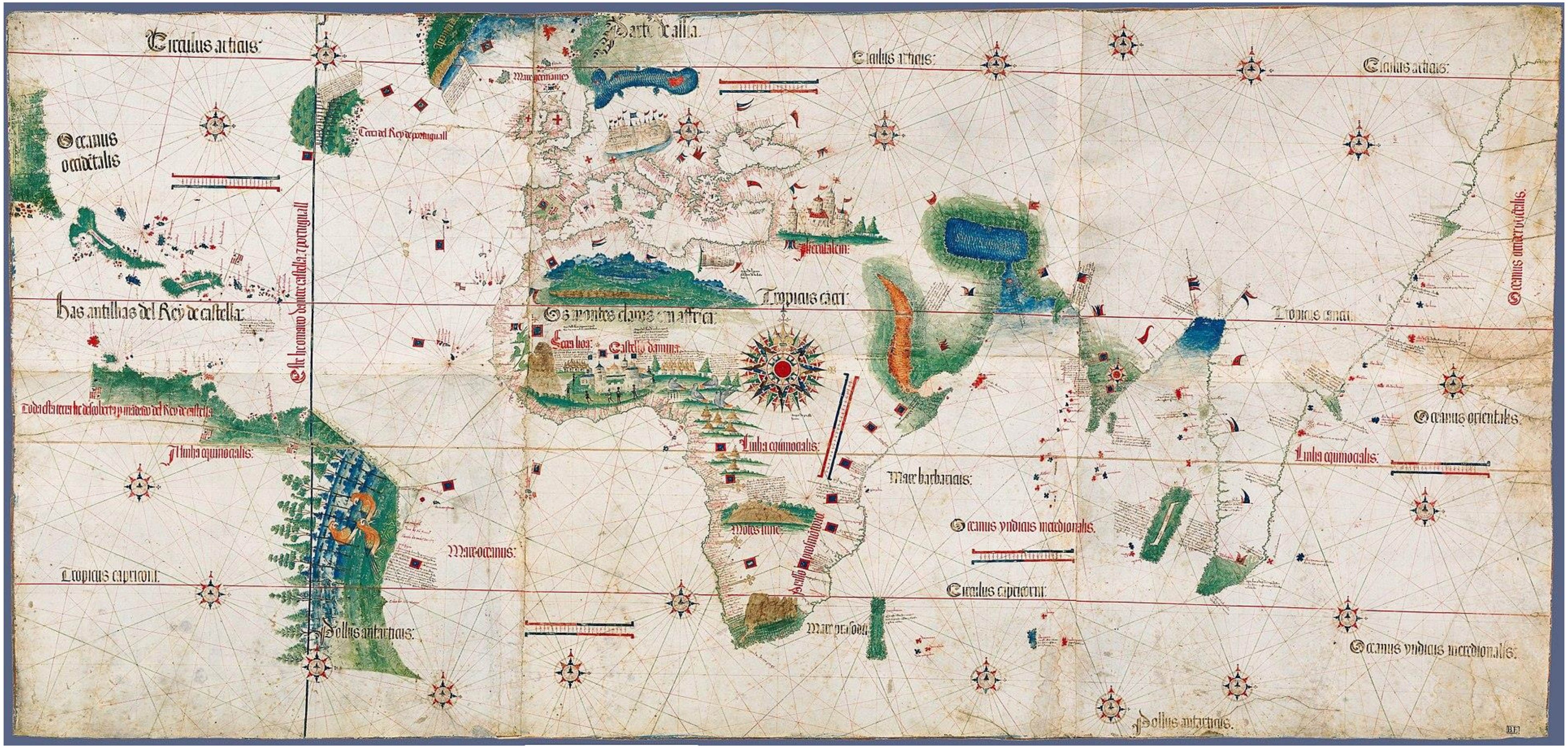

Fig. 11: The Cantino planisphere, completed by an unknown Portuguese cartographer in 1502, is one of the most precious cartographic documents of all time. It depicts the world, as it became known to the Europeans after the great exploration voyages at the end of the 15th and beginning of the 16th centuries to the Americas, Africa and India. It is now kept in the Biblioteca Universitaria Estense, Modena, Italy [30]

[30] Public Domain: Cantino planisphere (1502) - Cantino planisphere - Wikipedia

The Renaissance [31]

The period following the Middle Ages in Europe was called the Renaissance (French word for rebirth) by 19th-century historians. Several factors pave the way for the Renaissance in Italy and northern Europe, including the increasing failure of the Roman Catholic Church to provide stability in spiritual and civic life, the rise in importance of city-states and national monarchies, the development of national languages, and the breakup of old feudal structures.

The spirit of the Renaissance was first expressed by the movement called humanism, which is based on three main principles: human nature is the primary subject of study; all philosophies and theologies have an underlying unity; and individual human beings possess innate dignity. Through humanism secular scholars and others broke free of religious orthodoxy, engaged in free inquiry and criticism, and gained confidence in the potentials of human thought and creations.

A "proto-renaissance" occurred in Italy in the late 1200s and early 1300s, based on humanism and the work of St. Francis of Assisi, who rejected the formal Scholasticism, going out among the poor praising the beauties and spiritual value of nature. Artists were inspired by his example to take pleasure in the natural world around them and to study beauty as a path to the divine.

Though the discovery and exploration of new continents, the Copernican revolution and the invention of the printing press marked important new chapters in scientific study and communications, to many scholars and thinkers of the period, the Renaissance was primarily a time of the revival of Classical learning and wisdom after a long period of cultural decline. This revival led to a great flowering in architecture, painting, sculpture, and music.

The High Renaissance flourished from the early 1490s to 1527—when the sack of Rome by the armies of the Holy Roman emperor Charles V marked the end of the Renaissance as a unified historical period. The High Renaissance art in Italy revolves around Leonardo da Vinci (1452–1519), Michelangelo (1475–1564), and Raphael (1483–1520) and sees the transition from the rather flat and formal medieval art to beautiful perspectives and emotional presences (inner life comes through), in painting as well as sculpture. High Renaissance architecture recalls ancient Classical temple architecture with its columns and domes (St. Peter's Basilica in Rome, for instance). Composers (such as Josquin des Prez and Giovanni Pierluigi da Palestrina) develop polyphonic music, in which one or more melody lines are played at the same time.

As Italy was then a collection of kingdom, republics, and cities ruled by Dukes (like Milan), artists were a lot in demand, to show rulers' power and cultural superiority, and to promote their ideas. Among these Court artists, Leonardo is known as the classic "Renaissance man" because of his wide range of interests, including painting, drawing, sculpture, architecture, human anatomy, science, and engineering. His reputation as a painter is based on only a few works (*Mona Lisa*, *Last Supper*, etc.), but his talent eclipsed other artists', such as Francesco di Giorgio Martini (1439–1501), whose architectural treatise *Trattato di architettura* inspired Leonardo. Compiled at the end of the 16th century by the sculptor Pompeo Leoni, Da Vinci's *Codex Atlanticus* includes 1,119 leaves abundantly illustrated with sketches (from 1478 to 1519) and covers a wide range of subjects, from flying to weapons to musical instruments, and from mathematics to botany (Figures 12 and 13). His work epitomizes the absence of boundaries between art and science in a creative and imaginative mind.

[31] Source: Renaissance | Key Facts | Britannica and Renaissance | Timeline | Britannica

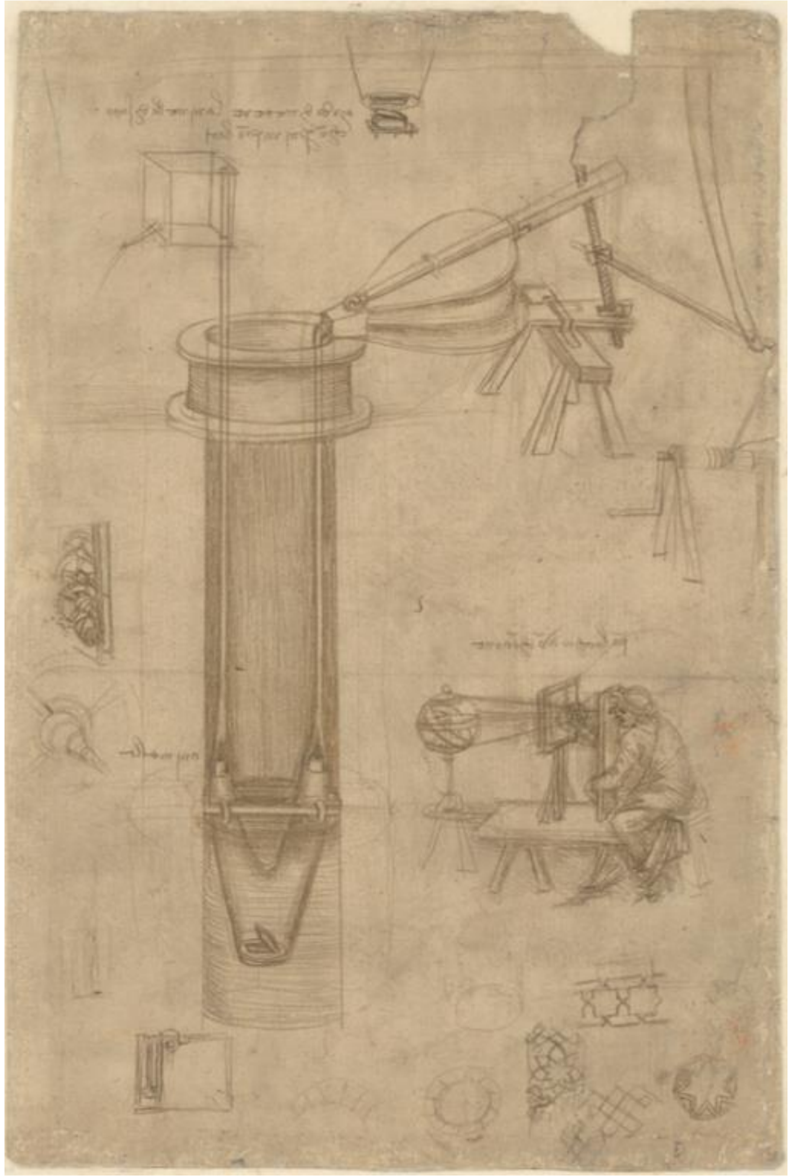

Fig. 12: *Atlantic Codex*, f. 5 recto: In the centre a bellows activated hydraulic pump. On the right: a man drawing an armillary sphere using a perspectograph (c. 1480-82).
Atlantic Codex (Codex Atlanticus), f. 5 recto - Veneranda Biblioteca Ambrosiana

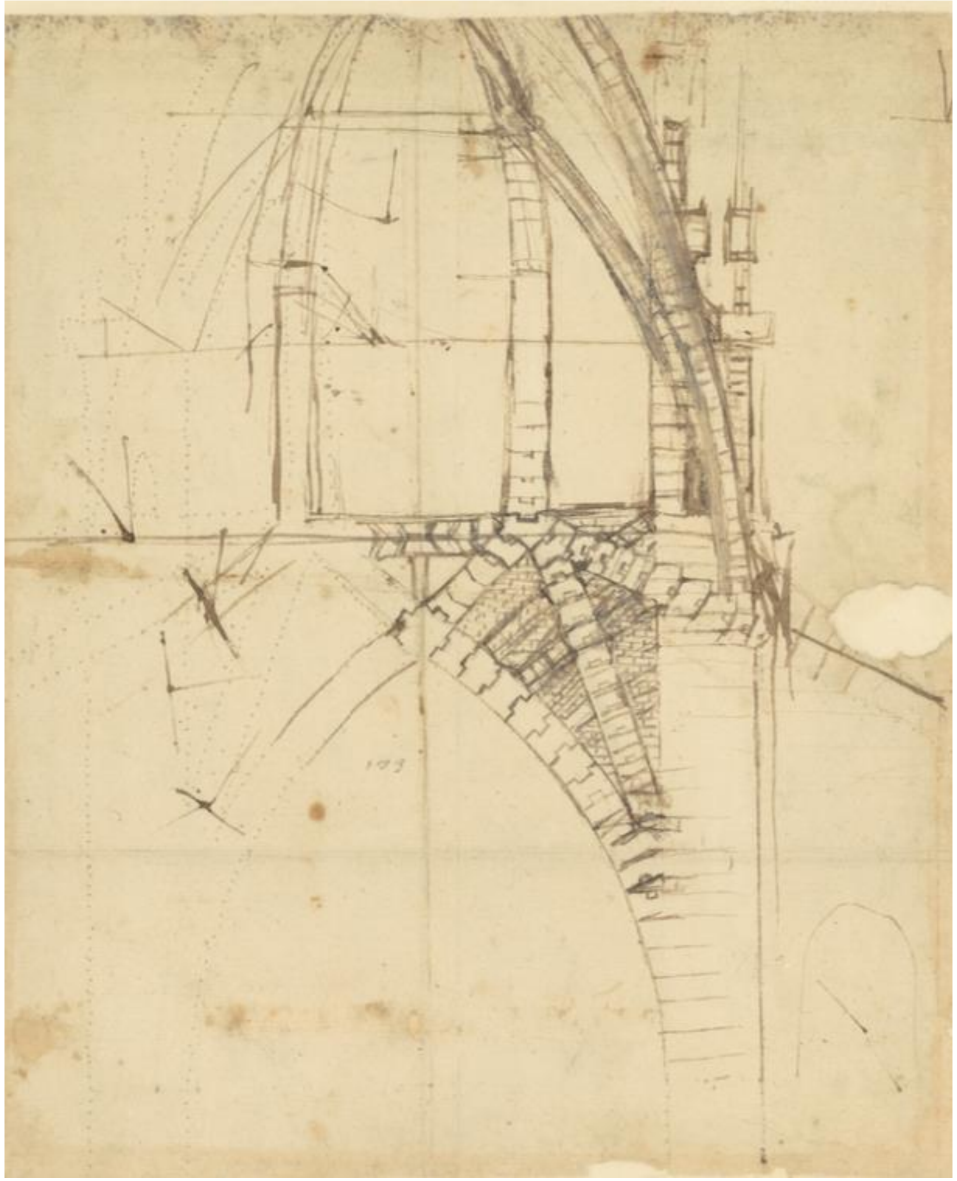

Fig. 13: *Atlantic Codex*, f. 851 recto: Section of the tiburio of the Duomo. The drawing shows the typical spolvero holes (c. 1487–1490).
Atlantic Codex (Codex Atlanticus) f. 851 recto - Veneranda Biblioteca Ambrosiana

The Vitruvian Man (see p. 10) combines principles of humanism, geometry, anatomy, and art (Figures 14 and 15). The circle and the square were long thought of as symbols of the divine and the earthly, respectively. The arrangement of the figure within the two shapes reflects the Renaissance humanist belief that the human body is a microcosm of the universe. By studying the proportions of the ideal human body, Leonardo and his contemporaries, like intellectuals of antiquity, imagined that they could infer the rules guiding the universe. Moreover, by applying geometry and his knowledge of anatomy—subjects held in high regard during the Renaissance—Leonardo was taking part in an effort to elevate the status of fine arts, which were then only regarded as crafts.[32]

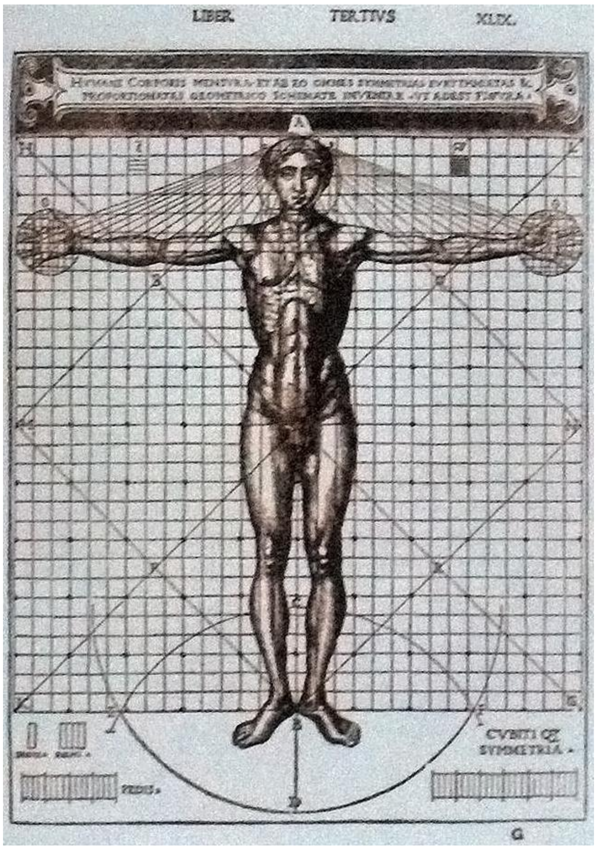

Fig. 14: Illustrated edition of *De architectura* by Cesare Cesarino (1521) [33]

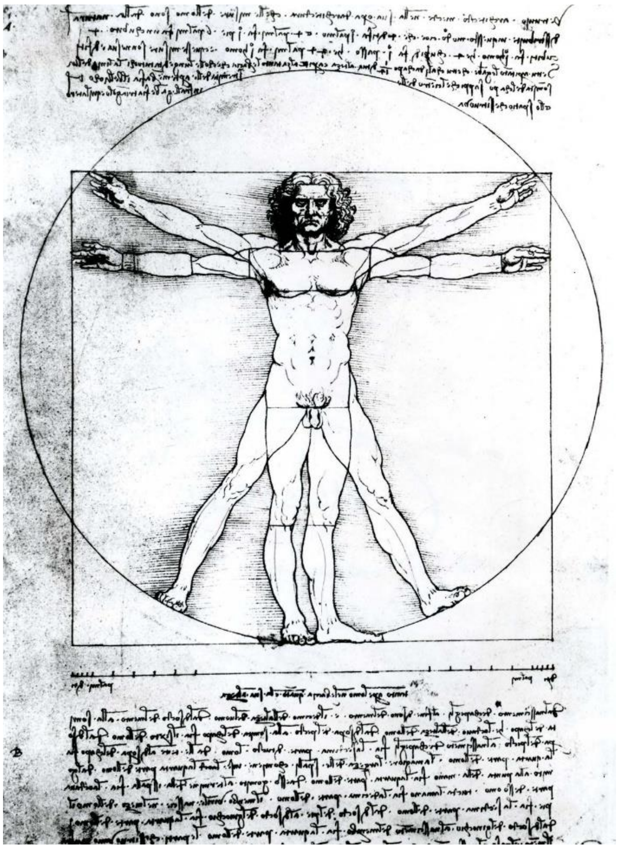

Fig. 15: Vitruvian Man by Leonardo Da Vinci (c. 1492) [34]

In 1543, *De Humani Corporis Fabrica Libri Septem* (*On the Fabric of the Human Body in Seven Books*), was published by Andreas Vesalius (1514-1564), an anatomist and surgeon, who taught anatomy through his own dissections at the University of Padua. Vesalius had a very skilled artist to work with him: never before had the human body been depicted so accurately. His book was a major advance in the history of anatomy over the long-dominant work of Galen and presented itself as such. Even the title page (Fig. 16) tells the reader that something special is happening: it shows the dissection of a woman in public, with hundreds of people crowding around. Vesalius stands in the middle; he is the only person looking out at the reader. The rest of the audience is either fascinated by the dissection or gossiping with each other. [35]

[32] Vitruvian Man | History, Drawing, Leonardo da Vinci, Meaning, & Facts | Britannica
[33] Public Domain: De Architectura030 - Vitruvius - Wikipedia
[34] Public Domain: man-Vitruvian-figure-study-canon-Leonardo-da.jpg (1166×1600) (britannica.com)
[35] William Bynum, *A little History of Sciences*, pp. 51-53

Fig. 16: Title page of *De Humani corporis fabrica* (1543) [36]

Vesalius's magnum opus presents a careful examination of the organs and the complete structure of the human body. This would not have been possible without the many advances that had been made during the Renaissance, including artistic developments in literal visual representation and the technical development of printing with refined woodcuts. Because of these developments and his careful, immediate involvement—he travelled to Basel, in Switzerland, to supervise the printing of the text and the making of illustrations—Vesalius was able to produce illustrations superior to any produced previously (Figures 17 and 18). [37]

[36] Public Domain: https://commons.wikimedia.org/w/index.php?curid=457251
[37] Public Domain: De Humani Corporis Fabrica Libri Septem - Wikipedia

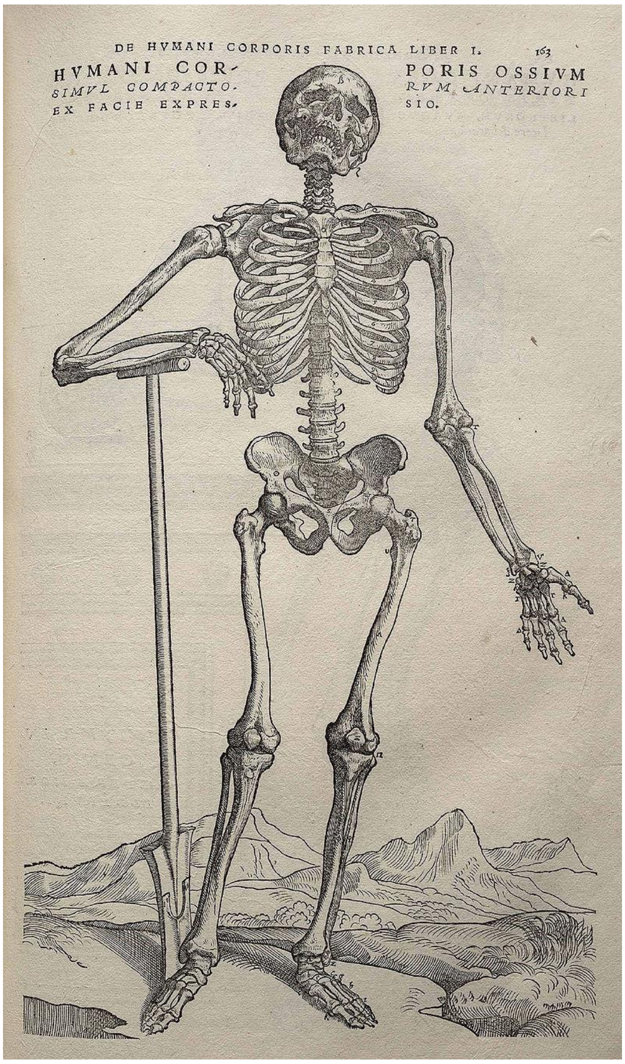

Fig. 17 : *De Humani corporis fabrica*, p. 163 [38]

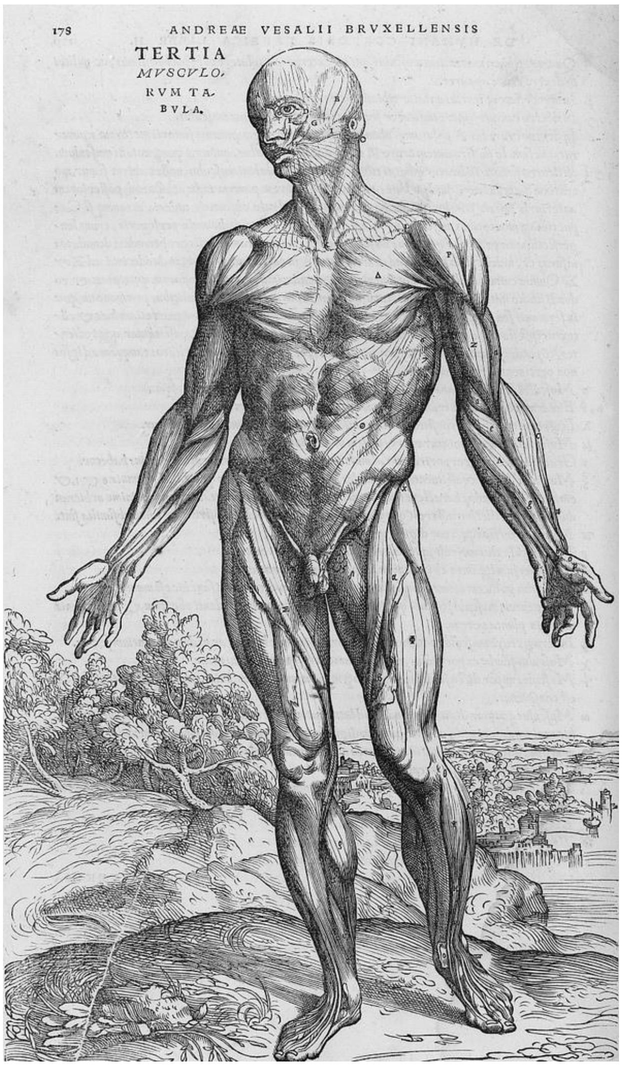

Fig. 18 : *De Humani corporis fabrica*, p. 178 [39]

Reciprocally, artists such as Leonardo da Vinci and Michelangelo dissected bodies in order to know how to paint them better: doctors were not the only ones who wanted to know about the structure of the human body.[40] During the Italian Renaissance, the bonding between science and art seems to have reached a zenith.

Meanwhile in Britain, after the Hundred Years War with France and the internal War of the Roses, the new king Henri VII (1485-1509) brought some peace and stability to the country and founded the House of Tudor. Both the Dutch scholar Erasmus (1469-1536) and the English lawyer Thomas More (1478-1535) were humanists and became close friends (Figures 19 and 20). Like many humanists, More believed that he should live in the world and try to change it for the better. This may have been why, in 1518, he became an important adviser to a magnificent, proud and powerful king. Indeed, when Henry VIII came to the throne in 1509, More joined a chorus of flattering praise for the 18-year-old king, declaring that 'sadness is at an end, and joy's before'. The athletic and well-educated young Henry impressed many people, including foreign ambassadors, and soon surrounded himself with a magnificent court.

[38] Source: Les Bibliothèques Virtuelles Humanistes - Fac-similés > Notice (univ-tours.fr)
[39] Ibid
[40] William Bynum, *A little History of Sciences*, p. 53.

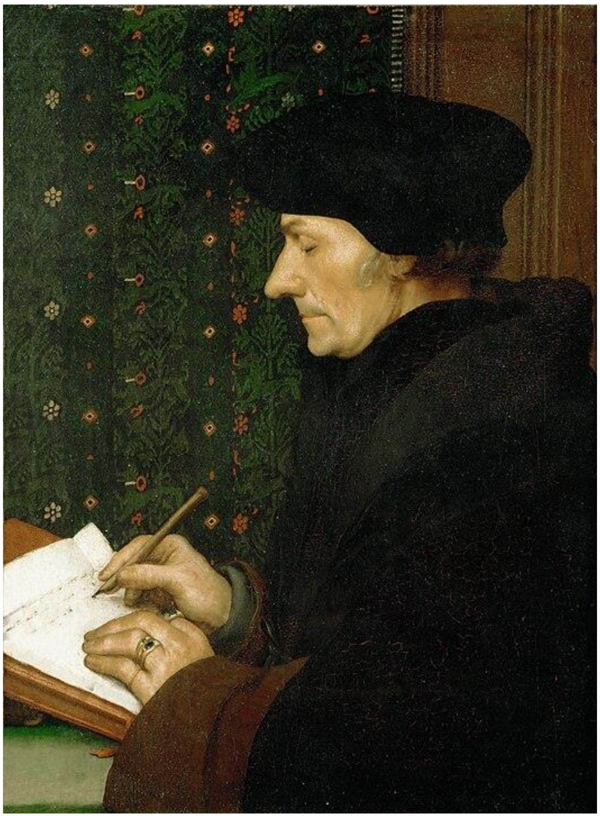

Fig. 19: *Portrait of Erasmus of Rotterdam Writing*, by Hans Holbein the Younger (1523), Le Louvre [41]

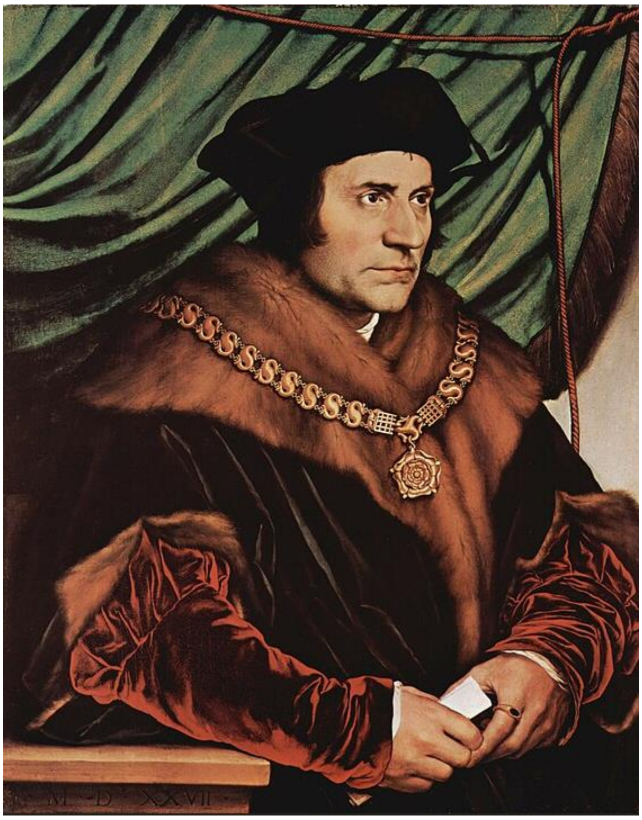

Fig. 20: *Portrait of Sir Thomas More*, by Hans Holbein (1527), The Frick Collection, New York [42]

Henri VIII enjoyed Thomas More's conversation and liked to discuss "astronomy, geometry, divinity… and sometimes… his worldly affairs… And other whiles would he in the night have him up into his leads [roof] there for to consider with him the… courses… of the stars and planets."

Hans Holbein the Younger (1497-1543), who painted Erasmus's and More's portraits, later became Henry VIII's painter and is considered as one of the greatest portraitists of the 16th century.
Scholars like Erasmus and artists like Holbein in England relied on patrons to provide them with a living. These might be the king or important men and women, such as Thomas More, who employed and befriended them in their households. Margaret Beaufort, the mother of Henry VII, gave money to colleges at both Oxford and Cambridge, and also helped Caxton the printer. The new learning which these patrons so admired spread slowly at first, among scholars in London, the universities of Oxford and Cambridge, and the three Scots universities of St Andrews, Glasgow and Aberdeen. The invention of the printing soon turned this trickle of new ideas and information into a flood.[43]

[41] Public Domain: File:Desidrius Erasmus by Hans Holbein.jpg - Wikimedia Commons
[42] Public Domain: File:Hans Holbein, the Younger - Sir Thomas More - Google Art Project.jpg - Wikimedia Commons
[43] *The History of Britain and Ireland*, pp. 163-166

Part 2: The Scientific Revolution

Since 1949, the Scientific Revolution has been the name given by some science historians and philosophers, such as Herbert Butterfield, to the period when the conceptual, methodological and institutional foundations of modern science replaced the scientific heritage of the ancient and medieval worldviews—personified by Aristotle, Ptolemy and Galen—in a radical or more gradual manner, depending on the discipline.

> Since that revolution overturned the authority in science not only of the Middle Ages but of the ancient world – since it ended not only in the eclipse of scholastic philosophy but in the destruction of Aristotelian physics – it outshines everything since the rise of Christianity and reduces the Renaissance and Reformation to the rank of mere episodes, mere internal displacements, within the system of medieval Christendom. Since it changed the character of men's habitual operations even in the conduct of the non-material sciences, while transforming the whole diagram of the physical universe and the very texture of human life itself, it looms …so large as the real origin both of the modern world and of the modern mentality that our customary periodisation of European history has become an anachronism and an encumbrance.[44]

While some historians mainly focus on the period between Copernicus *De revolutionibus orbium coelestium* (1543) and Newton's *Philosophiae naturalis principia mathematica* (1687), others include the Renaissance and the Enlightenment in this period (1500-1800), that Richard Holmes further extends to 'Romantic Science' or the 'second scientific revolution.' In his book *The Age of Wonder—How the Romantic Generation Discovered the Beauty and the Terror of Science*, he dates 'Romantic Science' between two celebrated voyages of exploration: Captain James Cook's first round-the-world expedition on the *Endeavour*, begun in 1768, and Charles Darwin's voyage to the Galapagos aboard the Beagle, begun in 1831.
However, all historians agree on the fact that Copernicus's work *De revolutionibus* was a breakthrough in astronomy and ushered in a fundamental change in viewing the world.

Though the notion of "Scientific Revolution" was later criticized in the 1980s and 1990s, this period is characterized by the acceptance of new criteria for explanation—stressing the "how" rather than the "why" that had characterized the Aristotelian search for final causes—and the development of observation instruments, such as the telescope, the microscope, etc. Based on measures and on more and more systematic experiments, these new sciences set the paradigm which is still dominant in our macroscopic world. Then in the 18th century, new mathematical methods, including the differential and integral calculus, would make obsolete the geometrical methods still used in Galileo's and Newton's works. In medicine and biology, though, there would not be such a break with the Classics (Aristotle and Galen) until the end of the 18th century, despite some progress and attempts to explain some physiological phenomena through mechanical or chemical factors. [45]

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[44] Herbert Butterfield, *On the Origins of Modern Science*, vii-viii
[45] Yves Gingras, *Histoire des Sciences*, pp. 8-9 and 61-62

2.1 New astronomy

We saw previously that Islamic and other astronomers had tried to correct the anomalies of the Ptolemean model of the universe, in which the earth is at the centre and the heavenly bodies move around it in perfect circles (see p. 8). Observing the "planets" (Mercury, Venus, Mars, Jupiter and Saturn, plus the sun and the moon) created more problems than the "fixed" stars, since they do not move as if they are circling the earth.

Nicholaus Copernicus (1473-1543) was a Polish bishop, whose true passion was astronomy. Although he spent many hours observing the heavens himself, he studied what other astronomers had seen and he thought that their difficulties could be solved by placing the sun at the centre and assuming that the planets rotated around it. Many puzzles, such as eclipses, or the strange forward and backward movements of the planets, fell into place. In 1514 he wrote a short manuscript and showed it to a few trusted friends, but did not dare publish it. He knew that his assertions that 'the centre of the earth is not the centre of the universe' and 'we revolve around the sun like any other planet' would shock people, so he quietly worked on his theory during the next three decades. Copernicus 's model had another significant consequence: it meant that the stars were much further away from the earth than Aristotle had assumed, thinking that space was fixed.
According to Robert Fleck[46], Michelangelo's Sistine Chapel *Last Judgement* (Fig. 21), completed in 1541, "analogizes Christ as a classical Apollonian sun superimposed over a radiant sun, positioned at the centre of a decidedly circular composition... As Copernicus himself recognized, the appeal of his heliocentric astronomy was aesthetic rather than pragmatic: the Copernican achievement was, in a very real sense, much like that of an accomplished draftsman. And just as in art, coherence, not proof, became the arbiter in science…" Indeed, though Copernicus's heliocentric system solved some well-known anomalies in Ptolemy's system, it created new, important anomalies, which would only be solved a century later with Newton's new paradigm in Physics. In this sense, we could say that Copernic's work acted as a transition between ancient and modern science.
In 1542, Copernicus finished his big book, *De revolutionibus orbium coelestium*, but then a sick man, he entrusted its printing to other priests, who published it in 1543. Two astronomers took his work further: the Danish Tycho Brahe (1546-1601) and his assistant, Johannes Kepler (1571-1630).

Tycho Brahe was inspired by Copernicus's insistence that the universe must be very large. In 1572, he noticed a new, very bright star in the night sky. He wrote about this *nova stella*, arguing that it proved that the heavens were not completely perfect and changeless. At that time, astronomers were usually astrologers too, thus Tycho Brahe made some astrological predictions: the appearance of that star could be nothing else than a divine sign. With the sponsorship of the King of Denmark, he built himself an elaborate observatory and equipped it with the most advanced tools—though telescopes had not been invented yet. In 1577 he followed the path of a comet; these were generally seen as bad omens, but for Brahe, the comet's path merely signified that the heavenly bodies were not fixed in their own spheres, since the comet cut across them. Tycho Brahe made important

[46] Robert Fleck, 'The Scientific Revolution in Art', pp. 142-146

discoveries about the positions and the movements of the stars and planets, although he had to close his observatory and move to Prague, where in 1597 he established a new one.

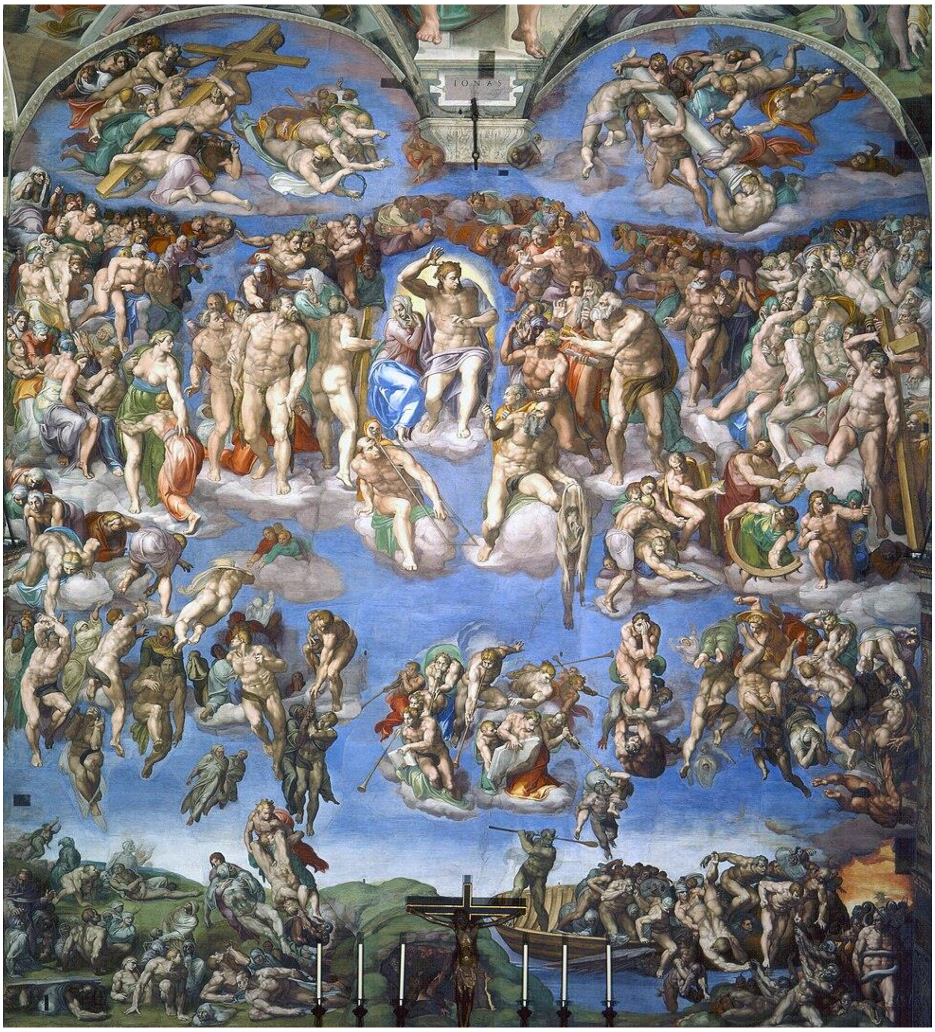

Fig. 21: *Last Judgement* (1536-41), by Michelangelo (1475–1564)[47]

Three years later, he made Kepler his assistant. A professor in mathematics, Kepler's former job was to prepare astrological previsions. In the Pythagorean tradition of the "harmony of the spheres"—a philosophical concept that regarded music as an embodiment of the harmonic structure of the universe—he searched the geometrical forms which rule the planets order, and published *Mysterium cosmographicum* in 1596 (see Fig. 22). *Harmonices mundi* was later published in 1619.
While Brahe never accepted Copernicus's heliocentric model, Kepler had a different outlook of the universe. When Brahe died in 1601, he left all his notes to Kepler, who took astronomy into an entirely new direction, elaborating three concepts that are still known as Kepler's laws.
First, using Brahe's observations of the planet Mars, Kepler discovered that Mars moves around the sun in an elliptical orbit. Not even Copernicus had challenged the ancient Platonic principle of circularity. In his article, Fleck argues that Kepler's "distorted" planetary orbits resonated with the curvilinear distortions typical of contemporary Baroque architecture, such as the elliptical plan of St Peter's Square, the large plaza located in front of St Peter's Basilica in Vatican City, designed by Gian Lorenzo Bernini and constructed between 1656 and 1667.

[47] Public Domain: File:Last Judgement (Michelangelo).jpg - Wikimedia Commons

Second, Kepler discovered that a planet's orbital speed varies inversely with its distance from the sun, moving faster when it is closer to the sun, and slower when it is away from it. It is the area of the arcs made as the planet moves in equal intervals of time that is constant, not the planet's speed. In 1609, he publishes a first synthesis of his research, intitled *Astronomia nova*. Ten years later, in the final section of *Harmonides Mundi*, he wrote what is called Kepler's third law, showing the mathematical relation between the time a planet takes to revolve completely around the sun and its average distance from the sun.

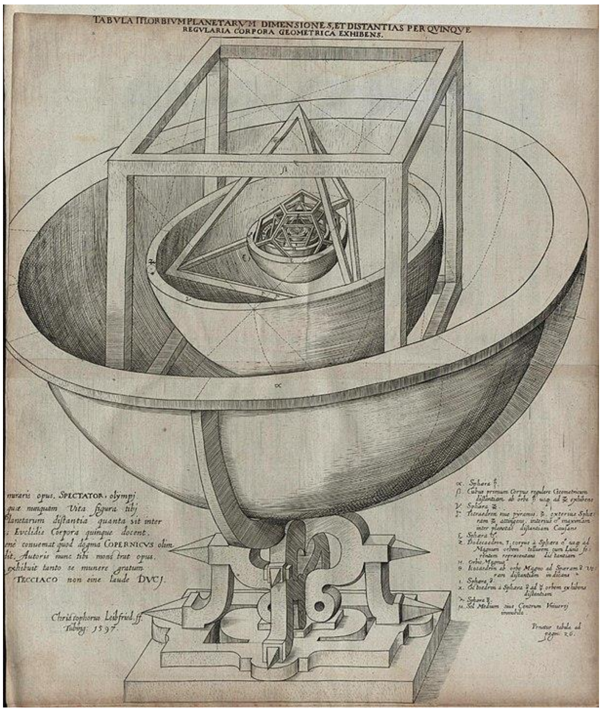

Fig. 22: Kepler's Platonic solid model of the Solar System from *Mysterium Cosmographicum* (1596)[48]

Fig. 23: *Personification of Astrology* (1650-55) by Guercino (1591–1666) [49]

Kepler reasoned that a force emanating from the sun must be responsible for moving the planets in their orbits, a real harmony in the clockwork motion of the solar system. Influenced by *De magnete*, that William Gilbert (1544-1603), a physician to Elizabeth I's court, had published in 1600, Kepler wrongly attributed this force to magnetism acting between a planet and the sun. However, he was the first to suggest that a *physical* force moved the planets. [50]

Since antiquity, the armillary sphere (Figures 23 and 24) was an instrument used in astrology and astronomy to represent the celestial sphere. During the Renaissance, this instrument became a symbol of power, knowledge and wisdom in the portraits of some European rulers, such as King Manuel I in Portugal (Fig. 25) and Elizabeth I in England. The armillary sphere also was an important navigational instrument for the Portuguese sailors during the voyages of exploration (see Fig. 11, p. 14), in the 15th and 16th centuries. King Manuel's royal standard, depicting an armillary sphere, became a symbol of the Portuguese Empire's global expanse, then Portugal itself. It can still be seen in the coat of arms of Portugal (Fig. 26) and its flag.

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[48] Public domain: Mysterium Cosmographicum solar system model - Platonic solid - Wikipedia

[49] Public Domain: Guercino Astrologia - Guercino - Wikipedia

[50] Robert Fleck, 'The Scientific Revolution in Art', pp 146-149; William Bynum, *A little History of Sciences*, pp. 60-61 and Yves Gingras, *Histoire des Sciences*, pp. 66-70

Fig. 24 [51]

Fig. 25 [52]

Fig. 26 [53]

In the following portrait of Queen Elizabeth I (Fig. 27), she wears a black gold-embroidered and bejewelled dress with armillary spheres. In her prayer book (see detail in Fig. 28), the drawing of the armillary sphere was possibly made by Elizabeth I herself. In the "Ditchley Portrait" (Fig. 29), the armillary sphere that hangs from Elizabeth's ear was a symbolic reference to her divine power and an emblem of the annual Accession Day Tilts.[54]

Fig. 27: portrait of Elizabeth I (circa 1580) [55]

Fig. 28: Detail of Elizabeth's prayer book, Royal Collections [56]

[51] Ptolemaic armillary sphere, c. 1450, Whipple Museum, Cambridge (own photo)
[52] Depiction of Manuel in prayer in his illuminated Gradual, c. 1500. Gent-Brügger Schule, Österreichische Nationalbibliothek, Public Domain: https://commons.wikimedia.org/w/index.php?curid=90888476
[53] Photo of the coat of arms of Portugal, ceiling decoration of the great hall, Palacio da Bolsa, Porto (own photo)
[54] Source: The Queen's Likeness: Portraits of Elizabeth I - National Portrait Gallery (npg.org.uk)
[55] Portrait of Queen Elizabeth I (English School, c. 1580): https://www.christies.com/en/lot/lot-5755418
[56] Source: Figure 13 on: https://britishartstudies.ac.uk/issues/issue-index/issue-17/an-early-impresa-miniature

Fig. 29: Detail of the Ditchley Portrait:
Elizabeth I with an armillary sphere in her ear [57]

Detail of the armillary sphere jewel

During Elizabeth I's reign, John Dee (1527–1609) was the court astronomer. As an antiquarian, he had one of the largest libraries in England at the time. A leading intellectual (he was a brilliant mathematician, antiquary and astrologer), Dee was one of the main architects of an imperial vision for England and he first coined the term 'British Empire,' arguing that it could become reality through maritime supremacy. Dee was also practical and, as well as being the first person to apply Euclidian geometry to navigation, he also built many of the instruments the early navigators needed on their journeys. Dee was also heavily involved in astrology, magic and the occult. He gave advice to Elizabeth I, including making a forecast for her reign based on her coronation date. She believed in his magical powers, and he was a trusted counsellor. [58]
But Dee was turned away when James I became king in 1603. Indeed, the Anglican Church and King James condemned magical studies as damnable.

William Shakespeare (1564-1616) might have been inspired by John Dee to create the character of Prospero, the powerful magician, in *The Tempest* (1610-11). Tudor and Stuart England's incipient empire is also an important historical context to understand that play: Prospero rules a distant island, imposing his superior technology (books, magic) and his language, as tools of conquest and domination. As the voluminous literature of European exploration was rife with tempests, wrecks, miracles, monsters, devils and wondrous natives, *The Tempest* may also be Shakespeare's oblique dramatization of Europe's age of discovery.[59]

[57] Source: NPG 2561; Queen Elizabeth I ('The Ditchley portrait') - Portrait - National Portrait Gallery
[58] Source: John Dee | Royal Museums Greenwich (rmg.co.uk)
[59] William Shakespeare, *The Tempest*, Introduction pp. 39-41 and pp. 62-63.

Galileo Galilei (1564-1642)

An Italian natural philosopher, astronomer, and mathematician who made fundamental contributions to physics, astronomy, and to the development of the scientific method, Galileo was also an artist and an artisan, in the tradition of his Renaissance elders.

Galileo attracted controversy throughout his life: his ideas challenged the physics and astronomy of Aristotle and the other Ancients. Though a good Catholic, he also believed that religion is about morality and faith, while science deals with the observable, physical world. Quoting a cardinal, he argued that the Bible teaches “how to go to heaven not how the heavens go.” This brought him into conflict with the Catholic Church: after he published his masterwork, the "*Dialogue Concerning the Two Chief World Systems*,” the pope turned against him, and the Inquisition forced Galileo to recant and to spend the remainder of his life under house arrest.

A teacher of mathematics and physics at the University of Padua (from 1592 to 1610), Galileo worked on the forces involved in moving objects. By 1609 he had determined that the distance fallen by a body is proportional to the square of the elapsed time (the law of falling bodies) and that the trajectory of a projectile is a parabola, both conclusions that contradicted Aristotelian physics.

That same year, he heard that in the Netherlands an instrument had been invented that showed distant things as though they were nearby. By trial and error, he quickly figured out the secret of the invention: not only did he make his own first telescope, but he quickly improved the instrument, taught himself the art of lens grinding, and produced increasingly powerful telescopes (Fig. 30).

Fig. 30: Two of Galileo's first telescopes; in the Museo Galileo, Florence.[60]

Fig. 31: Illustrations of the Moon, *Sidereus Nuncius* [61]

[60] Source: https://www.britannica.com/biography/Galileo-Galilei/Telescopic-discoveries#/media/1/224058/2916

[61] Public Domain: https://commons.wikimedia.org/wiki/File:Galileo%27s_sketches_of_the_moon.png

With his telescope, Galileo made many important observations: looking at the moon, he realized that it was not smooth, as it had been thought, but had mountains and craters; that Jupiter had four 'moons' like the earth had its moon; that the sun had dark areas or spots; that the Milky Way was actually composed of thousands of individual stars, very far away from the earth. In 1610, Galileo published a little book, *Sidereus Nuncius* (*The Sidereal Messenger*), in which he described his groundbreaking discoveries (Fig. 31). For Robert Fleck, Galileo's ink-wash drawings of the lunar craters are expertly rendered with special attention to the chiaroscuro effects of light and shadow.

His new science, in turn, inspired contemporary art: a telescope is represented in the following paintings, both entitled *Allegory of Sight* (Figures 32 and 33):

Fig. 32: Detail of *Allegory of Sight* (1617) by Jan Brueghel and P. P. Rubens. Museo del Prado, Madrid [62]

Fig. 33: Detail of *Allegory of Sight*, by Jusepe de Ribera (c. 1615), Franz Mayer Museum, Mexico.[63]

The telescope, however, was still difficult to use and its functioning was not well known. Some people thought Galileo's ideas were based on tricks played by his new instrument, because what could not be seen by the naked eye might not be there. Galileo had to try to convince people that what his telescope showed was real. Kepler started a theoretical and experimental investigation of telescopic lenses, and the resulting manuscript was published as *Dioptrice* in 1611.

Galileo's observations were good evidence for Copernicus being right about the moon revolving around the earth, and about the earth, moon and other planets all orbiting around the sun. He went to Rome in 1615 hoping to get the Church's permission to teach what he had learned, but he was forbidden to write about or teach heliocentrism. Giordano Bruno (1548-1600), an Italian philosopher, poet, alchemist, astronomer and cosmological theorist, had been tried for heresy by

[62] Public Domain, File:Jan Brueghel I & Peter Paul Rubens - Sight (Museo del Prado).jpg - Wikimedia Commons

[63] Public Domain: Allegory of Sight Jose de Ribera - The Five Senses (Ribera) - Wikipedia

the Roman Inquisition on charges of denial of several core Catholic doctrines, and found guilty, he was burned alive at the stake in 1600. Then Galileo thought that if he was careful to present the Copernican system only as a possibility, he would be safe. He thus published *Dialogue on the Two Chief World Systems*, his work on astronomy being written as a conversation between Aristotle, Copernicus and a third man acting as their host. After a 'trial' in 1633 that went on for three months, Galileo was forced to say his book was an error and the product of his vanity. The earth, he said in his signed confession, does not move and is the centre of the universe. He was put under house arrest for the rest of his life, but continued his work, publishing *Two New Sciences* (1638), one of the works which founded modern physics. He used mathematics to show that acceleration could be measured in a way that anticipated Isaac Newton's later famous work on gravity (see p. 35).
However, the news of Galileo's conviction quickly spread across Europe and sowed consternation, leading several supporters of Copernic to remain silent. René Descartes (1596-1650), who did not want any trouble with the Church, would not publish *The World* (1664) during his lifetime, because the Copernican position was central to his cosmology and physics.

The story of Galileo's conflict with the Church, as well as his last years living under house arrest, were depicted in art through the years, such as the 19th century paintings *Galileo before the Inquisition* (1847) by the French painter Joseph Nicolas Robert-Fleury (Le Louvre, Paris) or *Milton Visiting Galileo when a Prisoner of the Inquisition* (1847) by Solomon Alexander Hart (Wellcome Collection):

Milton Visiting Galileo when a Prisoner of the Inquisition (1847)[64]

[64] Source: Milton Visiting Galileo when a Prisoner of the Inquisition | Art UK

The poet John Milton (1608-1674) described his experience of Galileo's house arrest in his book *Aeropagitica*, an eloquent contribution to the historic English fight for freedom of speech[65]. Milton's epic poem, *Paradise Lost*, is replete with references to astronomy, such as: [66]

> …like the moon, whose orb
> Through optic glass the Tuscan artist views [*i.e., Galileo*]
> At evening from the top of Fesole,
> Or in Valdarno, to descry new lands,
> Rivers or mountains in her spotty globe. (Book I, ll. 287-291)
>
> Of amplitude almost immense, with Stars
> Numerous, and every Star perhaps a World [*Kepler's idea, see below*]
> Of destined habitation; (…) (Book VII, ll. 620-622)

Moreover, though the angel Raphael insists that he is only speculating ("Not that I so affirm", l. 117, "What if", l. 122) when addressing Adam, Milton, through Raphael's voice, seems to be endorsing Copernicus's and Galileo's heliocentric systems in the following lines:

> What if the Sun
> Be Centre to the World, and other Starrs
> By his attractive virtue and their own
> Incited, dance about him various rounds?
> Their wandering course now high, now low, then hid,
> Progressive, retrograde, or standing still,
> In six thou seest, and what if seventh to these
> The Planet Earth, so steadfast though she seem,
> Insensibly three different Motions move? (Book VIII, ll. 122-130) [67]

Francis Godwin's fiction *The Man in the Moone* (1638) was an important document to popularize certain astronomical ideas. Domingo's flight, unscorched, to the moon gives Godwin the occasion to ridicule the Aristotelian cosmology of realms of fire and his journey *through* space requires that it is not solid in any sense. The book's scientific awareness places it squarely in a 17th-century context: the moon has spots invisible to the unaided eye; diurnal rotation of the earth can be viewed from space; the fall of bodies to the earth may be compared to the attractive force of the loadstone, etc. In terms of physics and astronomy, Godwin brought to his work an enthusiasm for Gilbert's magnetism, and he probably recalled Galileo's sensational *Sidereus Nuncius* (1610) or Kepler's *Dissertatio cum Nuncio Sidero* (1610), the text in which Kepler had mooted the idea that the moon and other worlds were inhabited, a question that Galileo had prudently avoided. [68]
However, if the bishop Godwin promotes the theory of the diurnal rotation of the earth, he remains cautiously indecisive about Copernicus' heliocentrism, which also implies the annual and axial motions of the Earth: "I will not go so farre as *Copernicus*, that maketh the Sunne the Center of the Earth, and unmoveable, neither will I define any thing one way or other."[69] Indeed, Godwin uses a subtler way to convince his readers, reversing fact and fiction to give his 'essay of fancy' the

[65] Robert Fleck, 'The Scientific Revolution in Art', pp. 158 and 161.
[66] John Milton, *Paradise Lost*, respectively p. 12 and p. 86
[67] *Ibid*, pp. 190-1
[68] William Poole's introduction to Godwin's *The Man in the Moone*, pp. 17 and 39-40.
[69] Francis Godwin, *The Man in the Moone*, p. 94.

semblance of verisimilitude, in order to shift his readers' perspective on received cosmological notions.[70] Godwin's story became an international phenomenon, and its translation into French would inspire Cyrano de Bergerac's *Comical History of the States and Empires of the Worlds of the Moon and the Sun* (1648). [71]

Like Leonardo da Vinci a century earlier (see p.17), Peter Paul Rubens tried to elevate the status of artists—regarded as being of a lower class than scholars—in society. In Rubens's *Self-Portrait in a Circle of Friends from Mantua* below, the painter is near Galileo at the centre, among other scholars, and is looking out directly toward the viewer: including himself in such a learned circle may have been Rubens's primary motivation behind the painting. Moreover, the painter was a fan of astronomy and philosophy.

Self-Portrait in a Circle of Friends at Mantua, 1602, by Rubens (1577–1640), Wallraf–Richartz Museum[72]

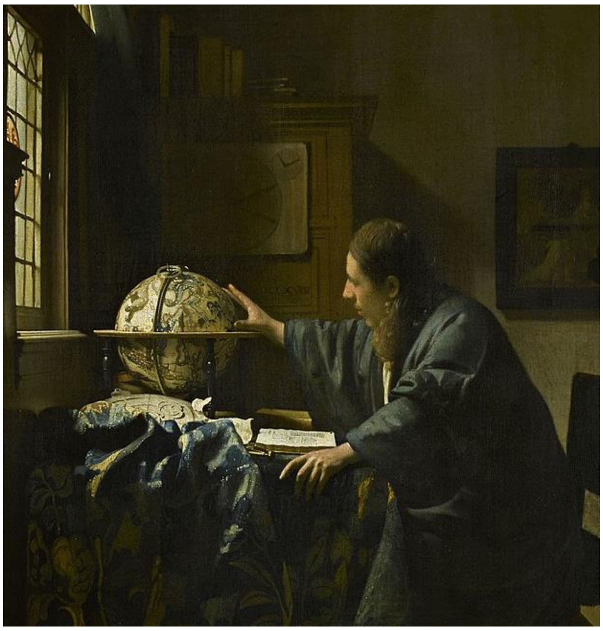
During the Dutch Golden Age (from 1588 to 1672), Dutch trade, scientific developments, art and overseas colonisation was among the most prominent in Europe. Painting of astronomers and scholars at work, such as Gerrit Dou's *Astronomer by Candlelight* (ca. 1665) and Jan Vermeer's paintings *The Astronomer* (ca. 1668) and *The Geographer* (ca. 1668), were popular in this new age of science. Astronomical treatises and maps, celestial and terrestrial globes, compasses to measure distances, all these instruments convey the extraordinary scientific curiosity of 17th-century scholars, who are shown here at work, the astronomers, either concentrating on a book or a globe, and the geographer surveying the world in his mind (see next page).

[70] See my research paper 'Real or imagined? The non-fictional and the fictional in Francis Godwin's *The Man in the Moon* (1638) and Jonathan Swift's *Gulliver's Travels* (1726), pp. 8-9: Gulliver & The Man in the Moone – The eternal student – anglophile version (eternal-student.com)

[71] William Poole's introduction to Godwin's *The Man in the Moone*, pp. 49-51.

[72] Public Domain: File:Peter Paul Rubens - Self-Portrait in a Circle of Friends at Mantua.jpg - Wikimedia Commons

Detail of *Astronomer by Candlelight*, late 1650s, by Gerrit Dou (Dutch, 1613 - 1675), Getty Museum Collection [73]



Detail of *The Astronomer* (c. 1668) by J. Vermeer (1632–1675), Le Louvre, Paris [74]

The Art of Painting (1665-66), by Jan Vermeer, Kunsthistorishe Museum, Vienna [75]

Detail of *The Geographer* (c. 1668), by J. Vermeer, Städel Museum, Frankfurt [76]

Vermeer's *The Art of Painting* (1565-66) shows an artist at his easel painting a model in his richly decorated studio, with a map of Low Countries on the wall and the objects on the table. Its composition and iconography make it the most complex of Vermeer's works. Compared with his contemporary paintings of scholars at work, this allegory of painting might suggest that Vermeer, like Rubens, sees the status of the artist equal to that of the scholars in society.

[73] Source: Astronomer by Candlelight (Getty Museum)
[74] Public Domain : File:Johannes Vermeer - The Astronomer - 1668.jpg - Wikimedia Commons
[75] Public Domain : Jan Vermeer - The Art of Painting - Google Art Project - L'Art de la peinture — Wikipédia
[76] Public Domain : File:Johannes Vermeer - The Geographer - Google Art Project.jpg - Wikimedia Commons

2.2 New physics

“Knowledge is power” and “I think, therefore I am”

In the century between Copernicus and Galileo, science turned the world upside down. The earth was no longer at the centre of the universe, and new discoveries in anatomy, physiology, chemistry and physics reminded people that the Ancient did not know everything. An English lawyer and politician, Francis Bacon (1561-1626), and a French philosopher, René Descartes (1596-1650), started thinking deeply about science itself.

Francis Bacon, an expert on English law, served Elizabeth I as well as King James I. An active member of the Parliament, he was also very enthusiastic about science and persuaded his sovereigns to use public money to build laboratories and provide places for scientist to do their research. “Knowledge is power”, he said, and science is the best way to achieve that knowledge: in *Novum Organum* (1620), he wrote “true directions concerning the interpretation of nature,” i.e., an account of the correct method of acquiring natural knowledge. Book II of *Novum Organum* gives the account of inductive reasoning—the core of Bacon’s philosophy of science: to avoid hasty generalization, Bacon urges a technique of “gradual ascent,” i.e., the patient accumulation of well-founded generalizations of steadily increasing degrees of generality, thus “loosening the hold on men’s minds of ill-constructed everyday concepts that obliterate important differences and fail to register important similarities”. The crucial point, Bacon realized, is that induction must work by elimination and not, as it does in common life and the defective scientific tradition, by simple enumeration. [77]

> But by far the greatest hindrance and distortion of the human intellect stems from the dullness, inadequacy and unreliability of the senses, so that things which strike the senses outweigh those which, even if they are more important, do not strike them immediately. Reflection therefore almost stops where sight does, and so things invisible attract little or no attention. Thus every operation of the spirits enclosed in tangible bodies lies hidden and escapes men’s notice. In the same way too every more subtle metaschematism in the parts of grosser bodies (…) evades detection; yet unless the two things just mentioned are sought out and brought to light nothing great can be done in nature as far as works are concerned. Again, the very nature of ordinary air and of the bodies which surpass it in tenuity (which are many) is practically unknown. For the sense is by nature a weak and wandering thing; and instruments to amplify and sharpen the senses do not count for much; but **all truer interpretation of nature is accomplished by means of instances, and apt and appropriate experiments, where the sense judges only the experiment while the experiment judges nature and the thing itself.** [78] (my emphasis)

In his utopia published posthumously, *The New Atlantis* (1626), Bacon also thought that scientist should form societies, or academies, so they could meet and exchange their ideas and observations.

Like Galileo, René Descartes was a Catholic who believed that religion should not come into the study of natural world. Much more of a practising scientist than Bacon, he tried to establish both science and philosophy on entirely new foundations. He was one of the first to abandon Scholastic Aristotelianism: applying an original system of methodical doubt, he dismissed apparent knowledge

[77] Source: Francis Bacon | Philosophy, Scientific Method, & Facts | Britannica
[78] Francis Bacon, *New Organon* book I, aphorism 50, in *Oxford Francis Bacon*, vol. XI, Oxford University Press, p. 87.

derived from authority, the senses, and reason and erected new epistemic foundations on the basis of the intuition that, when he is thinking, he exists; this he expressed in the dictum "Cogito, ergo sum" (in English "I think, therefore I am"). He developed a metaphysical dualism that distinguishes radically between mind, the essence of which is thinking, and matter, the essence of which is extension in three dimensions (for instance, human bodies, but also stones, planets, cats and dogs). Like Bacon, Descartes' general goal was to help human beings master and possess nature.
Mechanics is the basis of his physiology and medicine, which in turn is the basis of his moral psychology. Descartes believed that all material bodies, including the human body, are machines that operate by mechanical principles. The machines were matter, which could be understood by scientists in term of mechanical and chemical principles. Descartes had read the work of William Harvey (1578-1657) on the 'mechanical' actions of the heart and the circulation of the blood, and he believed that this provided evidence for his system. Founded on a rather atomist conception of matter, mechanist philosophy would also be foregrounded by Robert Boyle (1627-1691) in *The Sceptical Chymist* in 1661 (see p. 42).
Despite having some followers in his day, Descartes's ideas about how the universe works could not compete with Galileo's and Newton's, and few remember Descartes' physics today. However, not only do we still use some of his inventions in algebra and geometry, but because he promoted the development of a new science grounded in observation and experiment, he is generally regarded as the founder of modern philosophy.[79]

Isaac Newton and new dynamics.

The development of a new mechanist conception of nature, founded on an increasing role of mathematics in physics, led to the synthesis proposed by Isaac Newton (1642-1727). Though he was supposed to read the ancient masters when student at Trinity College, his favourites were Descartes, Boyle, and the other exponents of the new science, who viewed physical reality as composed entirely of particles of matter in motion and who held that all the phenomena of nature result from their mechanical interaction.
During the plague years (1665-66), university closed. Though working at home, Newton's achievements were amazing. He devised many experiments, but his greatest genius was in mathematics and how it could be used to understand more about the universe. As algebra and geometry are too limited to describe movement and gravity, he developed the calculus, a more powerful form of analysis that employs infinitesimal considerations in finding the slopes of curves and areas under curves. In 1666, though he shared his methods and results ("On the Methods of Series and Fluxions") with some acquaintances, he did not publish them. Meanwhile, the German philosopher and mathematician Gottfried Wilhelm Leibniz (1646-1716) invented the differential and integral calculus, a method based on algorithms while Newton's is based on geometry. Easier to use, Leibniz's analytical calculus would become the norm in Europe during the 18th century.
Besides mathematics, Newton furthered Descartes' work on light and wrote an essay, "Of Colours," which contains most of the ideas later elaborated in his *Opticks* (1704). It was also during this time that he examined the elements of circular motion and, applying his analysis to the Moon and the

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[79] Sources: Rene Descartes | Biography, Ideas, Philosophy, 'I Think, Therefore I Am,' & Facts | Britannica, William Bynum, *A Little History of Science*, pp. 74-80, and Yves Gingras, *Histoire des Sciences*, p. 78.

planets, concluded that the radially directed force acting on a planet decreases with the square of its distance from the Sun—which was later crucial to the law of universal gravitation. The world heard nothing of these discoveries, but, referring to Galileo, Kepler, and Descartes, he wrote to Robert Hooke (see p. 40): "If I have seen further it is by standing on the shoulders of giants."

But Newton himself was a giant, and he knew it. Elected to a fellowship in Trinity College in 1667, he would occupy the chair of mathematics from 1669 to 1696, his fame culminating in 1687 with the publication of *Philosophiae naturalis principia mathematica*, which is not only Newton's masterpiece but also the fundamental work for the whole of modern science.

The mechanics of the *Principia* was an exact quantitative description of the motions of visible bodies. It rested on Newton's three laws of motion: (1) that a body remains in its state of rest unless it is compelled to change that state by a force impressed on it; (2) that the change of motion (the change of velocity times the mass of the body) is proportional to the force impressed; (3) that to every action there is an equal and opposite reaction.

These three laws brought together the puzzles of earlier natural philosophers. In his book, Newton brought the heavens and earth together in one system, for his laws applied throughout the universe. He offered mathematical and physical explanations of the way the planets move and the way bodies fall towards the earth and made it possible to view the whole universe as a giant, regular machine.[80] However, contrary to Descartes, Boyle, and Leibniz, Newton would not try to give a mechanical explanation of gravity: 'hypotheses non fingo', meaning that the law of gravity is not a hypothesis, but the result of experimenting. Though he had obtained several results from these experiments, he considered that he had not discovered the reason or cause of gravity, and that any theoretical considerations would be 'invented' and not extracted from experiments.

As shown on next page, Newton is memorialized by a Baroque monument in Westminster Abbey, London, erected shortly after his death. It depicts the scientist reclining on a pile of books and attended by cherubs at his feet, playing with things that were of interest to Newton during his long and productive life: a prism that lay at the heart of his study of light, a reflecting telescope of his invention, a furnace signifying his alchemical studies, etc. Surmounting the whole, a female figure representing Astronomy, the Queen of Sciences, sits weeping on a celestial globe.

Newton was also memorialized in an imposing painting, *An Allegorical Monument to Sir Isaac Newton* (1727-29) by the Italian artist Giovanni Battista Pittoni, which depicts the figures of Minerva, Roman goddess of Wisdom, and other muses of science led by an angel towards a large urn containing Newton's ashes.[81] And a sort of miracle seems to be happening: a beam of light, with no apparent source, appears from a void above this urn. It is refracted through two prisms to become a rainbow-coloured 'cone': a physically impossible journey, one which suggests rather than illustrates Newton's proof that white light is made up of different colours.[82] Indeed, Newton's theory of colours drew considerable interest from painters.

After he died in 1727, Isaac Newton, the first scientist to be knighted, continued to be a towering figure in 18th-century Britain. In his epitaph for Newton, the poet Alexander Pope (1648-1744) wrote

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[80] Sources: Isaac Newton | Biography, Facts, Discoveries, Laws, & Inventions | Britannica, William Bynum, *A Little History of Science*, pp. 87-93, and Yves Gingras, *Histoire des Sciences*, p. 79-83.

[81] Robert Fleck, 'Scientific Revolution in Art', pp. 160-164

[82] See caption on: The Fitzwilliam Museum - An Allegorical Monument to Sir Isaac Newton (cam.ac.uk)

these witty lines: ‘Nature, and Nature’s laws lay hid in Night. / God said, Let Newton be! And all was light.’ Gradually the power of Newton’s experimental optics and laws of motion also took hold of European thought. In France, his reputation was helped by the poet, novelist and man of letters Voltaire (1694-1778). Coming back from England appreciating Newton’s achievement, Voltaire wrote a popular version of Newton’s ideas for ordinary people in French. *Candide* was also a gentle dig at the philosophy of Newton’s rival in the invention of calculus, Leibniz.[83]

Detail of Newton’s monument in Westminster Abbey [84]

An Allegorical Monument to Sir Isaac Newton, Fitzwilliam Museum, Cambridge[85]

Founded on 28 November 1660 by twelve scholars including Christopher Wren and Robert Boyle (see p. 42), the Royal Society, a learned society, was later granted a royal charter by King Charles II, and is the oldest continuously existing scientific academy in the world. Newton was one of the earliest Fellows of the Royal Society, elected in 1672, then its president, from 1703 to 1727.

From the foundation of the Royal Society, not only did its members want science to be open and public, but also that the new knowledge they uncovered and discussed at their meetings be *useful*. From the middle of the 17th century, the collective organization of scientists in several European countries stimulated the creation of specialized journals, such as *Philosophical Transactions* (1665), to spread scientific knowledge, in a much cheaper way than the publication of books, sometimes richly illustrated. These institutions established a system of *peer review*: a scientific article had to be

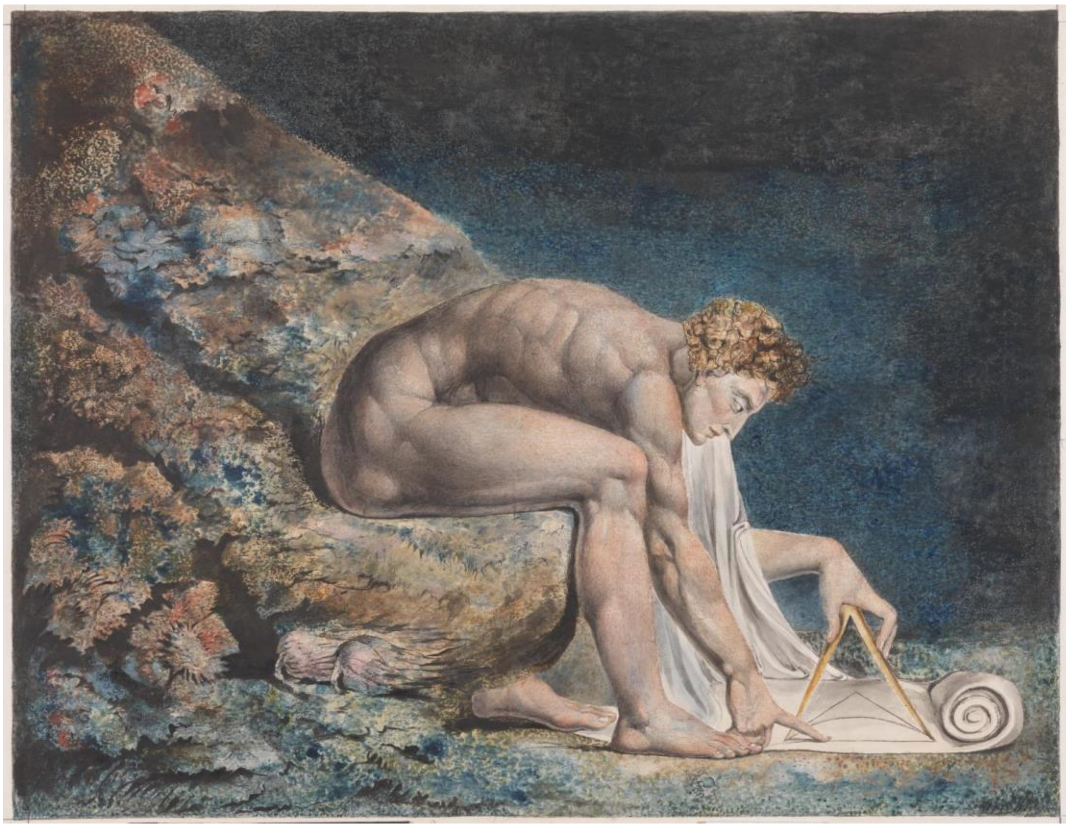
[83] William Bynum, *A Little History of Science*, pp. 100-106

[84] Source: Sir Isaac Newton | Westminster Abbey (westminster-abbey.org)

[85] Source: The Fitzwilliam Museum - An Allegorical Monument to Sir Isaac Newton (cam.ac.uk)

reviewed by a member of the society before its publication. Though the publication of books remained important in the 18th century, journals became the scientists' main tool for sharing the results of their research. And in the second half of that century appeared specialized journals, dedicated to a particular discipline, such as *The Mathematician* (1745), the *Journal de physique, de chimie et d'histoire naturelle* (1772), and the *Chemishes Journal* (1778). [86]
Interestingly, the Royal Academy of Arts (RA), also as an independent, privately funded institution led by eminent artists and architects, would only be founded in 1768 in Britain under the patronage of King George III, while in France, the various Royal Academies were all founded by Louis XIV under the influence of his advisers Mazarin and Colbert, around the mid-17th century: Painting and Sculpture in 1648, Dance in 1661, French Language in 1663, Sciences in 1666 and Music in 1669. From its foundation, the Royal Academy's purpose was to promote the creation, enjoyment and appreciation of the visual arts through exhibitions, education and debate. The RA Schools was the first institution to provide professional training for artists in Britain.

However, scientific advances and institutions were not unanimously praised in the 18th century. For instance, they are satirized in Jonathan Swift's book *Gulliver's Travels*: Chapter 5, in which Gulliver describes the grand academy of Lagado, has been interpreted as a charge against the Royal Society, its famous scientists, like Newton, and its "universal artists", like Robert Boyle. Through the description of the projectors' tasks, Swift ridiculed not only scientific inventors but also devisers of political, social, educational or commercial schemes. [87]



Newton (1795–c.1805), by William Blake [88]

[86] William Bynum, *A Little History of Science*, p. 83 and Yves Gingras, *Histoire des Sciences*, pp. 94-95
[87] See p.7 of my RP: Gulliver & The Man in the Moone – The eternal student – anglophile version (eternal-student.com)
[88] Drawing and captions on: 'Newton', William Blake, 1795–c.1805 | Tate

And at the end of the 18th century, the poet, painter, and printmaker William Blake (1757-1827) satirised Newton in one of his twelve large colour prints. Portrayed as a muscular youth, Newton seems to be underwater, sitting on a rock covered with colourful coral and lichen. He crouches over a diagram, measuring it with a compass. Blake believed that Newton's scientific approach to the world was too reductive. Here he seems to imply that Newton is so fixated on his calculations that he is blind to the world around him.[89]

Another Romantic poet, John Keats (1795-1821), though medically trained, felt that he was living in "cold and enfeebling times" when science was smothering imagination. In 1817, during a dinner-party, Keats agreed that Newton had "destroyed all the Poetry of the rainbow, by reducing it to a prism," [90] and, two years later, he wrote in *Lamia, book II*: [91]

> …Do not all charms fly
> At the mere touch of cold philosophy?
> There was an awful rainbow once in heaven:
> We know her woof, her texture; she is given
> In the dull catalogue of common things.
> Philosophy will clip an Angel's wings,
> Conquer all mysteries by rule and line,
> Empty the haunted air, and gnomèd mine—
> Unweave a rainbow… (ll. 229-237)

However, in an earlier sonnet, 'On First Looking into Chapman's Homer' (October 1816)[92], Keats had compared his first reading of Homer's poetry (in Chapman's translation) with Cortez' conquest of Central America (16th century) and with Herschel's discovery of Uranus in 1781 (see page 40):

> …
> Then felt I like some watcher of the skies
> When a new planet swims into his ken;
> Or like stout Cortez when with *eagle* eyes (*wond'ring* eyes in his first manuscript)
> He star'd at the Pacific—and all his men
> Look'd at each other with a wild surmise—
> Silent, upon a peak in Darien.

This is an illustration of the 'Eureka moment', the intuitive inspired instant of invention or discovery, for which no amount of preparation or preliminary analysis can really prepare. "Originally the cry of the Greek philosopher Archimedes, this became the 'fire of heavens' of Romanticism, the true mark of scientific genius, which also allied it very closely to poetic inspiration and creativity. Romantic science would seek to identify such moments of singular, almost mystical vision in its own history."[93]

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89 See captions on: 'Newton', William Blake, 1795–c.1805 | Tate
90 John Keats, *The Complete Poems*, p. 697: note to *Lamia*, Book II.
91 *Ibid*, p. 431. See also my research paper *John Keats, A Regency Poet*, p. 17: Keats, a Regency poet – The eternal student – anglophile version (eternal-student.com)
92 *Ibid*, p. 72.
93 Richard Holmes, *The Age of Wonder*, p. xvii

2.3 New instruments

The orrery, a planetarium of the modern era, became very popular from the beginning of the 18th century and was used both for teaching purposes and, for those who could afford them, recreation in the home.

Grand Orrery by George Adams, ca. 1750, Whipple Museum of the History of Science, Cambridge (own photo)

Table orrery, ca. 1783. Whipple Museum, Cambridge (own photo)

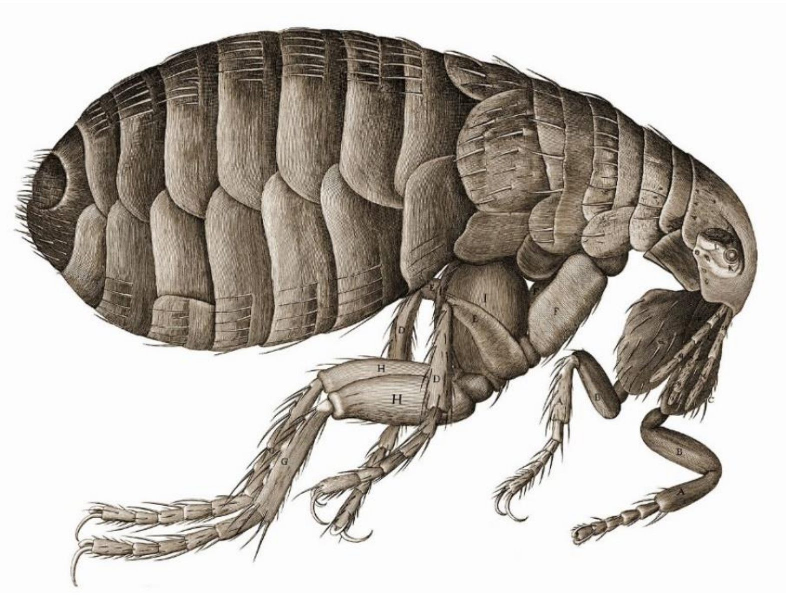
In the grand orrery above, Uranus and Neptune are not included, because they had not been discovered yet.

The Orrery, ca 1766, by Joseph Wright of Derby (1734–1797), Derby Museum and Art Gallery[94]

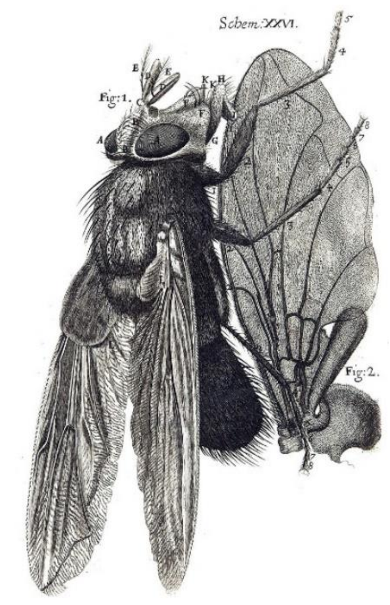
[94] Public Domain: File:Wright of Derby, The Orrery.jpg - Wikipedia

The popularity of that instrument was boosted by an enthusiasm for the work of Sir Isaac Newton whose universal theory of gravity had provided an explanation for the orbits of the planets. Interest in astronomy became even greater when Uranus was discovered in 1781 by William Herschel, leading to the manufacture of many more instruments of this kind.
To the people of the 18th century, these objects would have been used to convey the relatively new mechanistic explanations of the movement of the planets, but also inspired awe at our precarious position in this 'clockwork universe'. This is clearly expressed in the above, well-known painting of a red-gowned philosopher giving a lecture on the orrery in front of a fascinated family group.[95]
The source of light in the orrery, coming from the candle placed at the centre, in the place of the sun for the demonstration, also represents the source of light for the painting. Aspiring for his work to the higher status of History painting, Wright fully participates to the foregrounding of science during the period of the Enlightenment: what is worshipped here is not the Infant Jesus, but science.

I already mentioned the influence of the telescope in astronomy. Galileo had also understood that, by inversing the process, he could see details of microscopic objects such as a fly's head. A contemporary of Sir Isaac Newton, Robert Hooke (1635-1703) was Curator of Experiments at the Royal Society. He developed a microscope (see below), but his instrument experienced important chromatic and spherical aberrations, which would be corrected only during the 19th century.
In January 1665, Hooke published *Micrographia,* a book that Samuel Pepys described as "…the most ingenious book that ever I read in my life…." Pepys' enthusiasm was genuine. For many readers in the mid-seventeenth century, this was the first time they had seen large-scale illustrations of tiny creatures from everyday life. These were beings such as fleas, mites, and ants that appeared as specks to the naked eye but were revealed by the microscope to be as intricate as larger animals.[96]

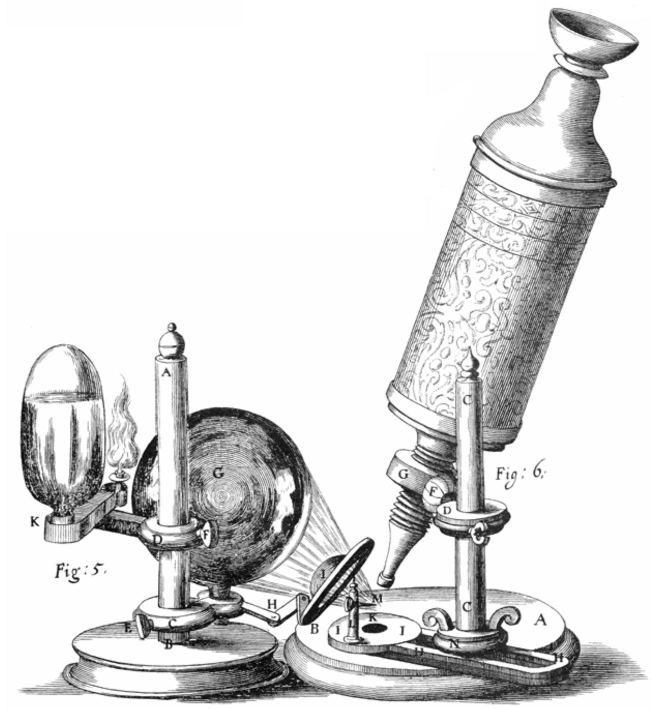


Micrographia, Schem. XXXIV - Of a Flea. National Library of Wales[97]



Micrographia, Schem. XXVI: A blue fly

[95] Orrery | History of Science Museum (ox.ac.uk)
[96] The Micrographia Microscope - Science Museum Blog
[97] Public Domain : https://commons.wikimedia.org/w/index.php?curid=117354



Robert Hooke's microscope, in *Micrographia* (1665)
Public domain, via Wikimedia Commons

Microscope "Marie type" ca. 1730-40, Museum of the Castle of Lunéville, France (own photo)

In the preface to *Micrographia*, Hooke argues for the utility of the microscope:

> The next care to be taken, in respect of the Senses, is a supplying of their infirmities with Instruments, and, as it were, the adding of artificial Organs to the natural; this in one of them has been of late years accomplisht with prodigious benefit to all sorts of useful knowledge, by the invention of Optical Glasses. By the means of Telescopes, there is nothing so far distant but may be represented to our view; and by the help of Microscopes, there is nothing so small, as to escape our inquiry; hence there is a new visible World discovered to the understanding. By this means the Heavens are open'd, and a vast number of new Stars, and new Motions, and new Productions appear in them, to which all the ancient Astronomers were utterly Strangers. By this the Earth it self, which lyes so neer us, under our feet, shews quite a new thing to us, and in every little particle of its matter, we now behold almost as great a variety of Creatures, as we were able before to reckon up in the whole Universe it self.

However, as mentioned previously, Hooke's microscope experienced important aberrations. In her book *Observations upon experimental philosophy* (1668), Margaret Cavendish (1623-1673), who had a different conception of nature than Hooke's, wonders to what extent the shapes of a magnified object, which is completely different from what is seen by the naked eye, are its real shapes or are just distortions created by the lenses, by the lights and shadows, and by the medium interposed between the object and the lenses. Because of the lenses, what we see might not be the natural object, but a transformed picture of that object, and if scientific knowledge is based on that picture, it might lead to false theories.[98]

[98] Source: University of Groningen, 'The Scientific Revolution', MOOC, Week 2.

Robert Boyle (1627-1691) was a preeminent figure of 17th-century intellectual culture. He was best known as a natural philosopher, particularly in the field of chemistry, but his scientific work covered many areas including hydrostatics, physics, medicine, earth sciences, natural history, and alchemy. When he helped creating The Royal Society of London, a club devoted to increasing knowledge, he and his fellows knew that they were doing something that Francis Beacon had called for half a century earlier. In 1659, he and Robert Hooke completed the construction of their famous air pump and used it to study the physical characteristics of many gases, including air, as well as its role in combustion, respiration, and the transmission of sound.

An Experiment on a Bird in an Air Pump, 1768, by Joseph Wright of Derby, National Gallery. [99]

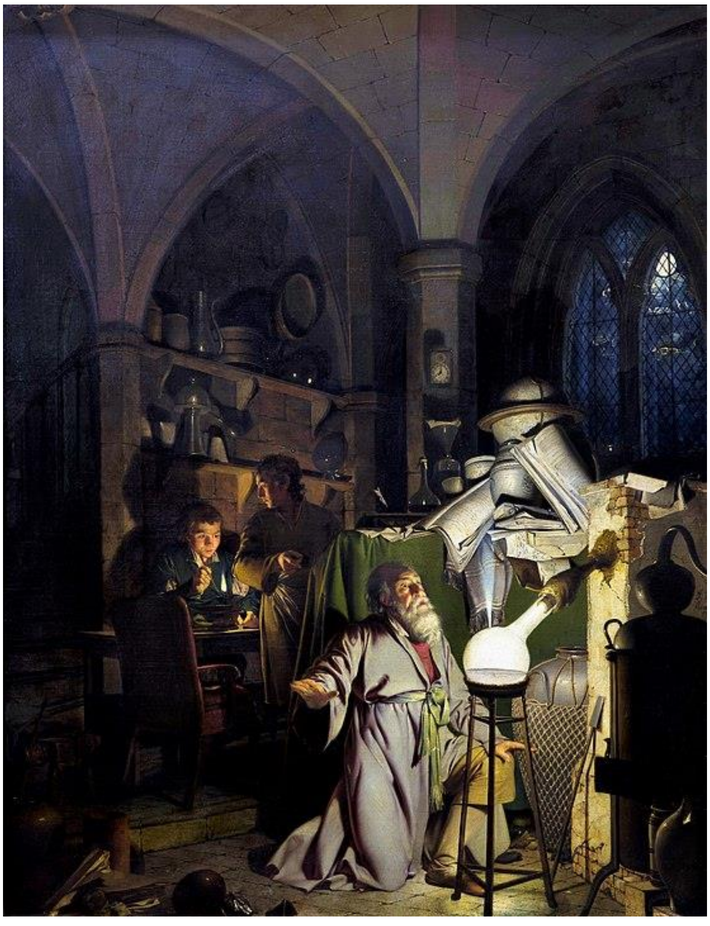
Joseph Wright, in this painting, uses a composition very similar to *The Orrery*. Its realism is striking, particularly Wright's characteristic attention to light and shadow, with the concentration of light dramatically conveying the process of scientific enlightenment that is taking place here. Through the attitude of men, though, Wright conveys a feeling that society seems to turn away from humanity, from life (including that of animals) to the profit of science. Indeed, using a rare and expensive bird for an experiment in which it is going to die is astonishing and seems to express Wright's critical view towards the Enlightenment. Though Wright's memorable paintings show these experimental and laboratory scenes as a series of mysterious, romantic moments of revelation and vision, they also ask whether Romantic science contained terror as well as wonder: if discovery and invention brought new dread as well as new hope into the world. We have certainly inherited this dilemma.[100]

[99] Public Domain, File:An Experiment on a Bird in an Air Pump by Joseph Wright of Derby, 1768.jpg - Wikipedia
[100] Richard Holmes, *The Age of Wonder*, p. xix.

All these new instruments soon spread and became standardized, manufactured by specialized artisans who sold them on the new market of scientific amateurs and physics cabinets of colleges and universities. Thanks to new instruments and the systematic use of accurate scales to precisely weight the substances, chemistry radically developed in the second half of the 18th century with scientists like Joseph Priestley (1733-1804) and the French scientist Antoine Lavoisier (1743-1794), the man who named oxygen and is still known as the 'father' of modern chemistry.

Believing that the language of chemistry must be precise, Lavoisier and three prominent colleagues published a new nomenclature of chemistry in 1787. Its aim was to put some order in the names of chemical substances, whose diversity still testified of the strong influence of alchemists' tradition. This reformed language of chemistry was soon widely accepted, thanks largely to Lavoisier's eminence and the cultural authority of Paris and the Academy of Sciences. Its fundamentals remain the method of chemical nomenclature in use today. Then in his *Elements of Chemistry* (1789), he described the precise methods chemists should employ when investigating, organizing, and explaining their subjects. It was a worthy culmination of a determined and largely successful program to reinvent chemistry as a modern science. [101]

The time of alchemy was then definitely finished: indeed, when J. Wright of Derby first exhibited *The Alchemist Discovering Phosphorus* in 1771, it disturbed 18th-century viewers and the painting was not sold. Wright reworked it in 1795, but the painting was only sold four years later, after his death.



The Alchemist Discovering Phosphorus, 1771-1795, by J. Wright of Derby, Derby Museum and Art Gallery [102]

[101] Sources: Yves Gingras, *Histoire des Sciences*, p. 86 ; William Bynum, *A Little History of Science*, pp. 118-119, and Antoine Lavoisier - Oxygen, Combustion, Chemistry | Britannica

[102] Public Domain: Joseph Wright of Derby The Alchemist - The Alchemist Discovering Phosphorus - Wikipedia

2.4 Natural history and classification

We saw previously that the invention of the printing press in the middle of the 15th century played an important role in the progresses of anatomy and botany, because it facilitated the reproduction of detailed visual representations of various parts of the human body, as well as those of plants and animals. But these discoveries in anatomy and physiology did not change fundamentally the existing theories of the living world and of medical practice, still influenced by Galen's theory of humours.
From the 16th to the 18th centuries, European explorers brought back new kinds of plants and animals from exotic parts of the world. From 600 plants described by Dioscorides in the first century, the number increased to more than 10.000 by Tournefort (1656-1708) at the end of the 17th century. The multiplication of dried leaf collections and botanical gardens, especially for medical purposes, furthered progress in botany. Natural theology, which aims to demonstrate God's work in the creation, also furthered the detailed study of plants and animals. Several systems were suggested to establish a natural order, reflecting God's plan.

During the 18th century, two naturalists dominated thinking on these issues, each choosing a different approach: the French naturalist, mathematician, and cosmologist Comte de Buffon (1707-1788) and his great rival, the Swedish doctor and naturalist, Carl Linnaeus (1707-1778).

Buffon held the position of *intendant* (director) at the King's Garden—now called *the Jardin des plantes*—in Paris. To him, there was no order in nature: 'Nature knows only the individual'. His aim was thus to describe the earth and all the plants and animals on it. All his careful research was collected in a massive work: *Histoire Naturelle, générale et particulière, avec la description du Cabinet du Roi* (English: *Natural History, General and Particular, with a Description of the King's Cabinet*) is an encyclopaedic collection of 36 large (quarto) volumes written between 1749 and 1804, initially by Buffon then continued in eight more volumes after his death by his colleagues.
Buffon attached much importance to the illustrations: nearly 2.000 plates adorn the work, representing animals with care given both to aesthetics and anatomical accuracy, with dreamlike and mythological settings[103] (see some examples from Book IV[104] on next page).

Linnaeus spent most of his life as a professor at the University of Uppsala, where he maintained a botanical garden, and sent many students all over the world to collect plants and animals for him. His great goal was to name accurately all the things that exist on earth, and to place them within 'the order of nature', he *classified* them, i.e., defined their essential characteristics. At the top of his grand scheme were three *kingdoms*: plants, animals and minerals, and he made a bold move by including human beings (*Homo sapiens*) among the animals. Under these kingdoms were *classes*, such as the vertebrates; within a class were *orders*, such as the mammals; then the *genus*, followed by the *species*. Below species, there was varieties: within the human species, there varieties were called 'races'.

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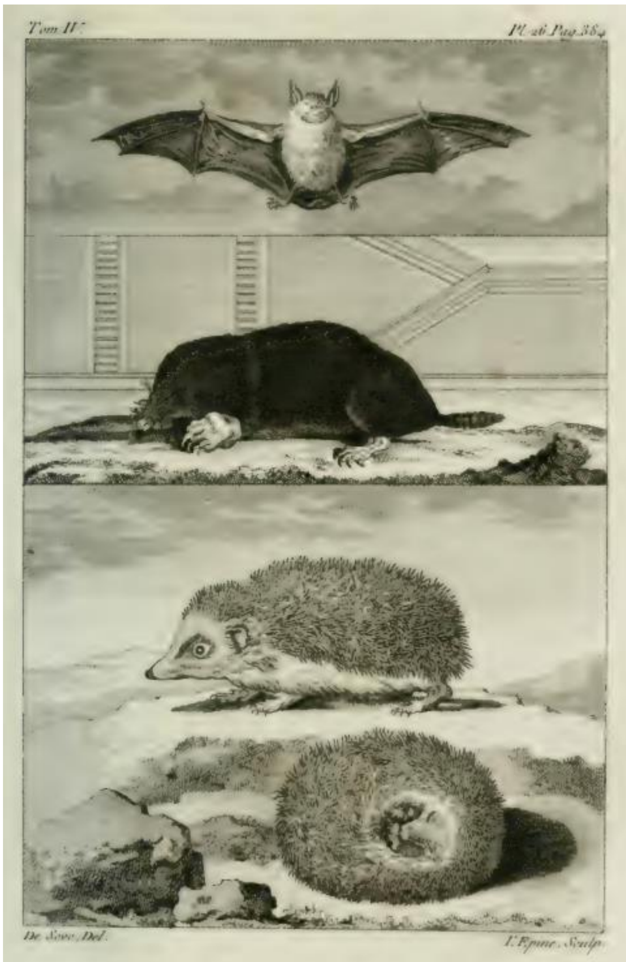
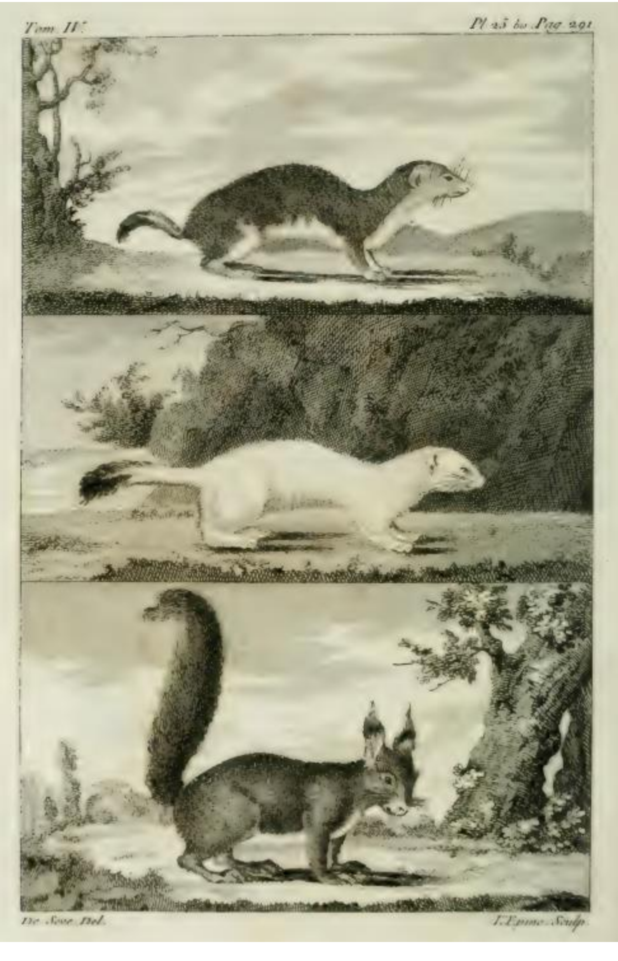
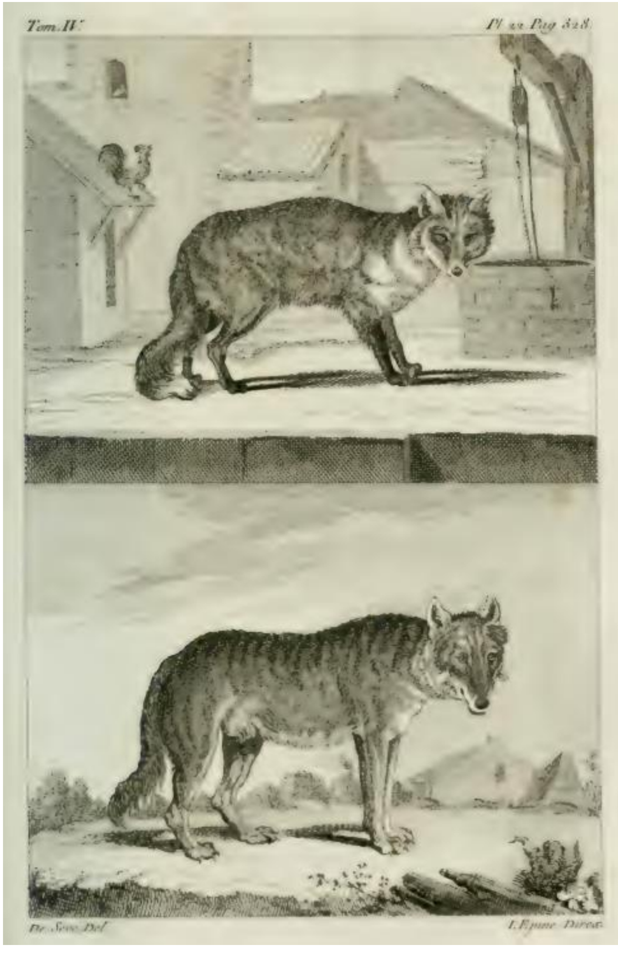
[103] Source: Histoire Naturelle - Wikipedia
[104] Buffon, *Histoire Naturelle*, Book IV, online: Histoire naturelle de Buffon (archive.org)


Tom. IV.
Pl. 7. Pag. 85.
De Seve. Del.
L'Epine. Sculp.


Tom. IV.
Pl. 26 Pag. 384
De Seve. Del.
L'Epine. Sculp.


Tom. IV.
Pl. 25 bis Pag. 291
De Seve. Del.
L'Epine. Sculp.


Tom. IV.
Pl. 22 Pag. 328.
De Seve. Del.
L'Epine. Direx.

Linnaeus devised a simple system for identifying each plant species, based on the male and female parts of their flowers. Even though it was only in plants, Linnaeus's sexual system disturbed some people and stimulated a few mildly erotic poems, such as Erasmus Darwin's "The Loves of the Plants" (see below). He did not believe that one species can evolve into another, but that God had specially created each separate species of plant and animal. He realized nonetheless that human beings were part of nature, and that the rules by which we study the natural world could also be used to understand mankind. However, Linnaeus's framework was changed a century later by another naturalist: Charles Darwin (see p.79).[105]

After he studied classics and mathematics at St. John's College, Cambridge, Erasmus Darwin (1731-1802) engaged in medical training. From 1756, he ran a flourishing medical practice in Lichfield, Staffordshire, and was elected a fellow of the Royal Society in 1761. The overriding characteristic of Darwin's work is his commitment to progress. A member of the Lunar Society, an informal yet influential group of scientific entrepreneurs involved in Britain's early industrialization, he invested in development projects and celebrated in flamboyant heroic couplets the technological innovations of factory owners, such as Josiah Wedgwood and Matthew Boulton (see § 3.1, p. 56).
Though Darwin's major early interests were medicine and invention, in the late 1770s he became fascinated by botany. He translated textbooks and composed "The Loves of the Plants" (1789), which mainly comprises elaborate footnoted verses extolling Linnaeus's taxonomic system. An immediate success, this erotic dramatization was later republished as the sequel to a poem called "The Economy of Vegetation" (1791) in the two-part *The Botanic Garden* (1791), strikingly illustrated by the Romantic artists William Blake and Henry Fuseli (1741-1825):

Henri Fuseli's frontispiece to *The Botanic Garden* [106]

…and *The Fertilization of Egypt* (p. 234 on the eBook)

[105] Yves Gingras, *Histoire des Sciences*, pp. 86-87, and William Bynum, *A Little History of Science*, pp. 108-112
[106] Source: DarwinGardenFrontispiece - The Botanic Garden - Wikipedia

The following illustrations by William Blake, are extracted from pages 228 and 232 of *The Botanic Garden*, in its eBook version: The Botanic Garden (archive.org):

Meadia.

Amaryllis formosissima.

Apocynum androsæmifolium.

Dionæa Muscipula.

Hedysarum gyrans.

Erythrina Corallodendron.

Gloriosa Superba.

Cypripedium.

By embracing Linnaeus's sexualized language, which anthropomorphizes plants, Darwin intended to make botany interesting and relevant to the readers of his time. Darwin emphasizes the connections between humanity and plants, arguing that they are all part of the same natural world, and that sexual reproduction is at the heart of evolution (ideas that his grandson, Charles Darwin, would later turn into a full-fledged theory of evolution).

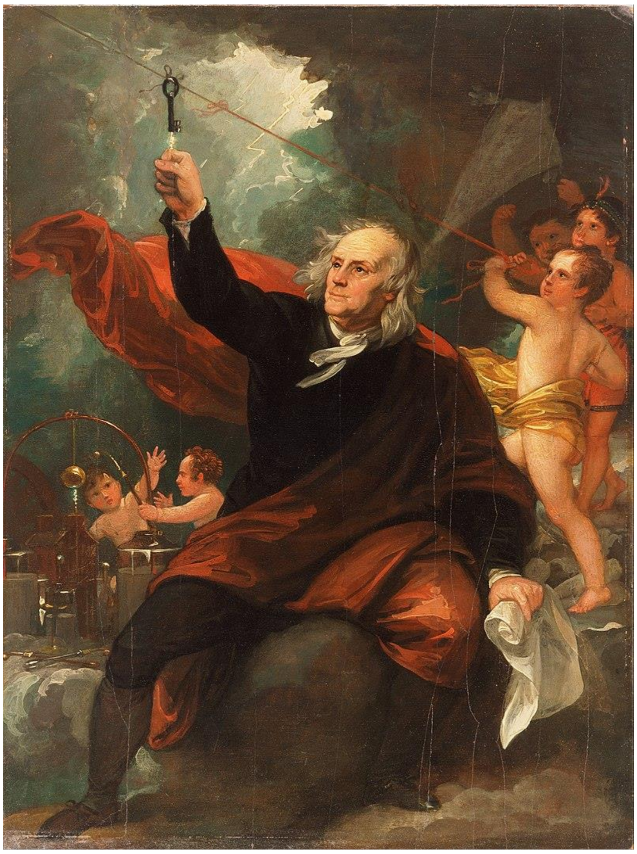
Darwin also sought progress through introducing scientific techniques into agriculture (*Phytologia*, 1800) and in natural history and medicine (*Zoonomia or The Laws of Organic Life*, 1794–96). His work initially enjoyed great success but fell out of favour because of his unorthodox views on evolution and the ornate didacticism of his poetry.

However, he deeply influenced his contemporaries and successors. The Shelleys commented on his importance for Mary's novel *Frankenstein*, and Charles Darwin studied his grandfather's work closely. Although a description of the world as "one great slaughterhouse, one universal scene of rapacity and injustice" might seem a fitting image for competitive natural selection, it was created not by Charles Darwin but by his grandfather, Erasmus.[107]

[107] Sources: Erasmus Darwin | British Physician & Natural Philosopher | Britannica, and The Botanic Garden - Wikipedia

2.5 Electricity and magnetism

From the beginning of the 18th century, scientists started to investigate seriously the phenomena of electricity and magnetism (see Gilbert, p. 24), which could produce entertaining effects and had been popular topics for scientific lectures as well as after-dinner games.



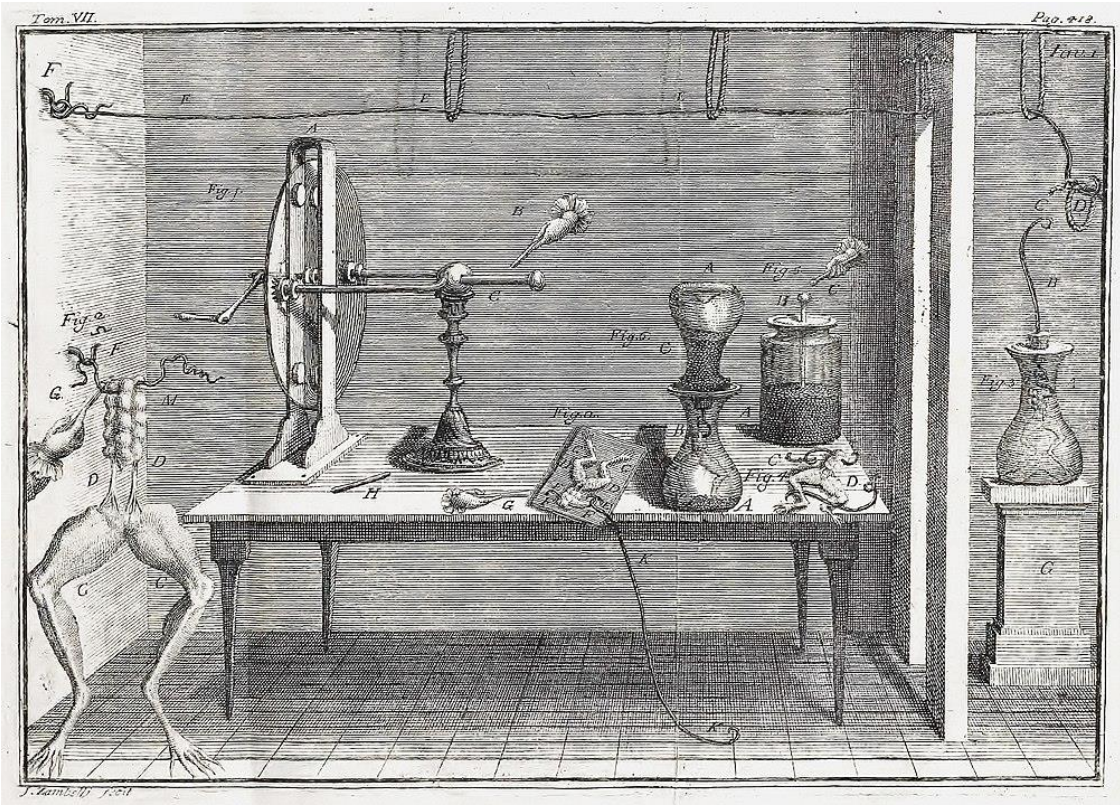
Benjamin Franklin Drawing Electricity from the Sky (c. 1816), by Benjamin West (1738–1820), Philadelphia Museum of Art [108]

Benjamin Franklin (1706-1790), an American polymath, brought some order to the many theories flying about electricity. He devised an experiment with a kite, which convinced him that the electricity of lightning was like the electricity of Leyden Jars. As a practical consequence, he showed that a metal pole with a sharp point conducted electricity to the ground, thus if a such pole were placed on the top of a building, with an insulated conducting body leading from it all the way down to earth, lightning would be conducted away from the building, avoiding it to catch fire if struck by lightning.

Laura Bassi (1711-1778), an Italian physicist and academic at the University of Bologna, was the first woman to have a doctorate in science. She popularized Newton's mechanics and Franklin's ideas about electricity in Italy, when both topics were not yet part of the university curriculum. In 1752, conducting an experiment which modelized the conduction of a lightning electricity to the earth, she convinced the Pope to equip the roof of a tower with a lightning rod, to protect the building from fire.

[108] Public Domain: [Benjamin West, English (born America) - Benjamin Franklin Drawing Electricity from the Sky - Google Art Project - Benjamin Franklin - Wikipedia]

The study of electricity was one of the most exciting areas of scientific research in the 18th century. Three scientists particularly contributed to its development: Luigi Galvani (1737-1798), a doctor at the University of Bologna, Alessandro Volta (1757-1827), a scientist from Como, and André-Marie Ampère (1775-1836).



Experiment *De viribus electricitatis in motu musculari*, by Luigi Galvani (1791)[109]

Galvani discovered that what he called "animal electricity", seemed to be essential in the functioning of animals' muscles and bodies in general. His findings, though captivating the imagination of some contemporary writers (see p.65) also attracted criticism from Volta, who tried to discredit the interpretation of Galvani's experiments.

Volta discovered that he could produce a continuous electric current through the layers of what he called a "pile", a set of successive layers of zinc and silver (or copper), separated by wet cardboard. News of Volta's invention created sensation in Britain and France, where Napoleon Bonaparte decorated the Italian physicist: indeed, the voltaic pile would play an essential part in the early 19th century chemistry (see p.62).

Ampère developed a theory about what he called "electrodynamics." Despite the complexity of a subject bringing together electricity and magnetism, Ampère's simple but elegant experiments showed that magnetism was in fact electricity in motion. His work underpinned the later discoveries of Faraday and Maxwell (see pp. 69-70).[110]

[109] Public Domain: Luigi Galvani Experiment - Luigi Galvani - Wikipedia

[110] William Bynum, *A Little History of Science*, pp. 94-99.

According to Robert Fleck, the history of art reflects the achievements of the Scientific Revolution, through works produced contemporaneously as well as later pieces that continue to reflect back on the period. “For no other period before, and rarely since, has so much art focused on science, either directly in depicting scientists and their tools and discoveries, or indirectly in reflecting underlying themes and core principles shared in the arts and sciences.” Though I share with him the opinion that some artists, such as Joseph Wright of Derby, “this most science-minded painter in this most science-conscious century,” or Vermeer, for instance, reflected in their works the advancement of knowledge and science happening in their contemporary societies, I will not follow his general argument that “clearly, artists *appreciated—and continue to recognize—the revolutionary character of what occurred in the sciences*, adding merit to *understanding this era as truly revolutionary*…” (my emphasis). To me, later paintings or sculptures rather romanticize the scientific achievements of previous centuries, as 19th-century painters romanticized the Middle-Ages in the Troubadour style: *Milton Visiting Galileo when a Prisoner of the Inquisition* (see p.29) for instance, focuses more on the story of the encounter between Galileo and Milton and the contrast between both protagonists, than on Galileo’s scientific achievements.

To give a more balanced view on the relationship between science and art, I also pointed out that some artists and poets criticized, rather than praised, scientific advances and institutions; even some of Wright of Derby’s paintings include a critical view of the scientific experiments that he describes so realistically. To me, the fact that artists chose interesting, even fascinating, contemporary subjects like scientific experiments for their paintings, or included beautiful objects like scientific instruments in the composition of their allegories, is less a proof of their recognition of the *revolutionary character* of what occurred in science, than the evidence of the artists’ greater sensitivity to capture society changes before most people.

Finally, even if art might have consciously focused more on science during the Scientific Revolution than before or after, I also demonstrated that art and sciences were already strongly intertwined during the Renaissance, and I intend to show in the next part of this research paper that they also closely interacted during the Industrial Revolution and the 19th century.

Part 3: The Industrial Revolution and the 19th century

According to Richard Holmes, the scientific revolution of the late 17th century had promulgated an essentially private, elitist, specialist form of knowledge. Its *lingua franca* was Latin, and its common currency mathematics. Its audience was a small (if international) circle of scholars and *savants*. 'Romantic science', with a new commitment to explain, to educate and to communicate to a general public, inaugurated a new age of the public scientific lecture, the laboratory demonstration and the introductory textbook. Science began to be taught to children, and the 'experimental method' became the basis of a new, secular philosophy of life, in which the infinite wonders of Creation (whether divine or not) were increasingly valued for their own sake.
In this period, the elite monopoly of the Royal Society was challenged. Scores of new scientific institutions, mechanics institutes and 'philosophical' societies were founded, most notably the Royal Institution (1799), the Astronomical Society (1820), and the British Association for the Advancement of Science (1831). [111]

At the turn of the 19th century, natural science was mostly in a state of empirical observation and experimentation. Apart from astronomy, optics and mechanics, which had well-established mathematical foundations, other natural phenomena, such as heat, electricity and magnetism remained essentially qualitative and empirical knowledge, even though they may have been measured sometimes. In the second half of the 19th century, these different fields merged within a single discipline, physics, which replaced "natural philosophy." More based on mathematics, and on observations made with more sophisticated instruments, physics became the domain of specialized researchers. Geology and Natural History remained closely related, while chemistry and biology, an emergent discipline, developed on their own bases with specific concepts.

Meanwhile, in the period from 1760 to 1830, an Industrial Revolution happened in Britain, changing the country's agrarian and handicraft economy into one dominated by industry and machine manufacturing, bringing about significant societal changes: urbanization, industrial labour, and new social classes. That revolution, driven by scientific advances, started with steam, or rather, taming its energy to turn it into power. Coal, iron and textile were the first industries to develop in the 18th century. Lancashire and Yorkshire replaced East Anglia and the South-West of England as the major cloth-making regions. The iron industry moved north from Sussex and the Forest of Dean to the coalfields of the Midlands, Scotland and Wales. The regions which had traditionally been the poor, underpopulated fringes of British life were transformed; they became the crowded centres of wealth and vitality.

The following paintings of Keighley (in 1839) and Bradford (in 1849), in West Yorkshire, show how the growth and industrialization of cities rapidly transformed the landscape, the pastoral surroundings giving way to the smoking factories:

[111] Richard Holmes, *The Age of Wonder*, p. xix

View of Keighley (1839), by John Bradley (1787–1844) [112]

View of Bradford (1849), by William Cowen (1791–1864), Bradford Museums and Galleries[113]

[112] Public Domain: File:John Bradley View of Keighley 1839.jpg - Wikimedia Commons
[113] Source: View of Bradford | Art UK

In the Shropshire village of Coalbrookdale, Abraham Darby (1678–1717)—the first in what would become a distinguished dynasty of iron masters—had pioneered an innovative method of iron smelting. Using coke made from local coal to fuel furnaces rather than charcoal, Darby's discovery made the mass production of cast iron economically viable. With this breakthrough in production, the iron trade in Britain accelerated and local industry began to flourish[114].
In the following painting, *Coalbrookdale by Night* (1801), made by the French artist Philip James de Loutherbourg (1740–1812),

> [the] vivid nocturnal scene captures the dramatic tension at the heart of the Coalbrookdale site. The glowing furnaces sit at the centre of the picturesque Shropshire landscape, competing with the romantic moonlight. Male figures toil over the smelted iron—half heroes, half demons—watched by the woman and child, spectators from a threatened rural idyll. De Loutherbourg conjures the marvel of industry, but also the flames of hell, in a painting that is imbued with the spectacle that viewers knew from his work in the London theatres. The painting is based on sketches made on two tours from Shropshire to Wales in 1786 and 1800 observing industrial workings. *These were bought by the artist JMW Turner*, an avid fan of de Loutherbourg's works.[115] *(my emphasis)*

Coalbrookdale by Night, 1801, by Philip James de Loutherbourg (1740–1812). Science Museum, London.[116]

Once a village of farmers and shepherds, typical of Wales—a rural country where villagers added to their income by quarrying, mining and cloth-making, Merthyr was also dramatically transformed in the late 1750s by the arrival of ironmasters, drawn by the coalfields and the fast-flowing streams that would drive their waterwheels. By 1815, Richard Crawhay's Cyfarthfa ironworks at Merthyr Tydfil had become the largest in the world.[117]

[114] Source: History of Iron Bridge | English Heritage (english-heritage.org.uk)
[115] Source: Coalbrookdale by Night by Philippe Jacques de Loutherbourg | Science Museum Group Collection
[116] Public Domain: Philipp Jakob Loutherbourg d. J. 002 - Coalbrookdale by Night - Wikipedia
[117] *The History of Britain and Ireland*, p. 286.

Crawshay's Cyfarthfa Ironworks (1817), by Penry Williams (1802–1885)
Amgueddfa Cymru – Museum Wales, Department of Industry [118]

Print from a watercolour painting by George Robertson of Richard Crawshay's Nant-y-glo ironworks in 1788 [119]

And the above watercolour translates visually what Benjamin Malkin, a visitor to the South Wales ironworks developed by Richard Crawshay, witnessed in 1804. About the ironmaster's house, Malkin wrote:

[118] Source: Crawshay's Cyfarthfa Ironworks | Art UK
[119] Source: nantyglo_ironworks.jpg (700×461) (thomasgenweb.com)

> [It] is surrounded with fire, flame, smoke and ashes. The noise of the hammers, rolling mills, forges and bellows incessantly din and crash upon the ear… The machinery of this establishment is gigantic; and that part of it, worked by water, among the most scientifically curious and mechanically powerful to whom modern improvement has given birth.[120]

The idea of preserving rural life in peril emerged with the Industrial Revolution, but as a radical voice amidst the triumphant capitalism in Victorian Britain. If the social and ecological impacts of industrialisation were particularly addressed by the rural poet John Clare and the rebellious poet William Blake, William Wordsworth and John Ruskin would become important actors in the birth of ecology in Britain. Indeed, Ruskin evolved from an art critic to a radical social critic, when he became obsessed by the damage wrought by rampant industrialism on both landscape and human welfare. Some Victorian novels, such as Dickens's *Hard Times* and Mrs Gaskell's *Mary Barton* and *North and South* address the devastating social consequences of the Industrial revolution on workers. Some of the Pre-Raphaelite painters also felt concerned with social problems and the poor, as in Henry Wallis' painting *The Stone Breaker* (1857), which depicts a manual labourer, worn out by his work:

The Stone Breaker (1857), by Henry Wallis (1830-1916) [121]

This concern would become more pregnant in the Arts and Crafts Movement, led by William Morris (1834-1896), whose artistic thoughts, first inspired by Ruskin's theories in *The Stones of Venice*, would turn towards social reforms and Socialism.

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[120] *The History of Britain and Ireland*, p. 286.

[121] Public Domain: Fichier:Wallis The Stonebreaker.jpg — Wikipédia (wikipedia.org)

3.1 From heat to thermodynamics

Since the early 1700s steam engines had been used to pump water out of mines, but the power to turn the wheels which drove the machinery in iron foundries and textile workshops was provided by humans, animals or water. James Watt (1736-1819), a scientific instrument manufacturer in Glasgow, did not invent the steam engine, but discovered ways to make it work much more powerfully and with much less fuel. In 1775, he joined forces with a Birmingham manufacturer, Matthew Boulton (1728-1809), whose engineers provided the skills needed to build the machine Watt had designed. By 1781, Boulton and Watt had made an engine that could turn wheels. Steam engines created a vast demand for fuel, called into employment multitudes of miners, engineers, shipbuilders and sailors, and caused the construction of canals and railways.[122] In that modern world, factories, trains and ships would use the heat from coal in their furnaces to produce steam to drive the engines.

Their work also led scientists to investigate a basic law of nature, helping them see that heat was not a substance, as Lavoisier had thought, but a form of energy.
The French and the British were great rivals at that time, and a young French engineer, Sadi Carnot (1796-1832) wanted France to catch up. He was concerned with steam engine's *efficiency*, between the power produced and the energy needed to boil the water and turn it into steam. When he demonstrated that efficiency cannot be perfect (<1), his result summarized a deep law of nature, explaining why 'perpetual motion' machines cannot exist in the real world. Later in the 1840s and 50s, other scientists introduced a new system in physics: *entropy*—which is a measure of the molecular disorder, or randomness, of a system—and investigated many phenomena linked to energy, a study called *thermodynamics*. They realized that energy cannot be created out of nothing, nor can it completely disappear. All they could do with energy was to make it change from one form to another and use this process to produce some work. This result became known as the principle of conservation of energy. The physicist J. P. Joule (1818-1889) demonstrated that heat and work are directly related in ways that can be expressed mathematically. To measure the heat, or rather the temperature of an object, Fahrenheit (1686-1736) and Celsius (1701-1744) invented thermometers, with different scales, that we still use today. Then William Thomson (1824-1907), who was later given the title of Lord Kelvin, invented another scale, using very precise measurements and scientific principles. Its defining point is "the triple point of water", which occurs when the three states of water—ice (a solid), water (a liquid) and water vapour (a gas)—are in 'thermodynamic equilibrium'. Water freezes at 273.16 Kelvin (as compared with 0 degrees in the Celsius scale and 32 degrees in the Fahrenheit scale). But at the 'absolute zero', an impossibly cold temperature, all motion, all energy stops.
These scientists helped to explain both the science and the practical workings of all kinds of engines. As the 19th century progressed, the three discoveries mentioned above became the three laws of thermodynamics: the conservation of energy, the 'law' of entropy, and the absolute stillness of atoms at absolute zero. [123]

[122] *The History of Britain and Ireland*, pp. 288-89.
[123] William Bynum, *A Little History of Science*, pp. 169-174.

The invention of the steam engine and advancements in transportation expanded artists' horizons. Painters like J.M.W. Turner (1775 – 1851) embraced these innovations. For instance, his work, "*Rain, Steam and Speed – The Great Western Railway*," (1844) captured the dynamic energy of industrial progress:

> Turner frequently painted scenes of contemporary life and was particularly interested in industry and technology. As he often used new forms of transport, including steam trains, it is unlikely that the painting is a rejection of modernity. Instead, he saw both the train and the bridge as subjects worthy of being painted. Turner further emphasises the theme of speed by including two small details. On the river on the left, you can see a small boat and, barely visible near the right edge of the picture, a man drives a horse-drawn plough. Both the boat and the plough are examples of relatively slow, non-mechanised activity. As in *The Fighting Temeraire*, Turner contrasts the pre-industrial with the modern.

Rain, Steam and Speed – The Great Western Railway (1844), J.M.W. Turner, National Gallery, London [124]

In *The Fighting Temeraire*, the hulk of an old sailing ship, the Temeraire, is towed by a paddle-wheel steam tug to a place where it was to be scrapped. Set against a blazing sunset, the last voyage of the *Temeraire* takes on a greater symbolic meaning, as the age of sail gives way to the age of steam.[125]

[124] Caption and picture: Joseph Mallord William Turner | Rain, Steam, and Speed - The Great Western Railway | NG538 | National Gallery, London

[125] Caption and picture : Joseph Mallord William Turner | The Fighting Temeraire | NG524 | National Gallery, London

The Fighting Temeraire (1838-9), J.M.W. Turner, National Gallery, London

As bridges, factories, and railways became symbols of progress, industrial architecture and engineering marvels also influenced artists, who found beauty in these structures, highlighting the geometric forms and monumental scale of industrial buildings.
The fusion of natural beauty and industrial activity around the Severn Gorge attracted many artists and writers. Richard Warner, a writer and priest, described Coalbrookdale in 1801 as ‘a scene in which the beauties of nature and processes of art are blended together in curious combination’. Indeed, near Coalbrookdale, nestled in a spectacular wooded gorge, stands a monument to British industry: the world’s first iron bridge. Crossing the River Severn, it was completed in 1779 and opened to traffic in 1781:

The Iron Bridge by William Williams (1780), commissioned by Abraham Darby III.[126]

[126] Public Domain: William Williams The Iron Bridge - The Iron Bridge - Wikipedia

The unveiling of the Iron Bridge brought new visitors, who marvelled at its scale and ingenuity: “It must be the admiration, as it is one of the wonders, of the world.” (John Byng, traveller and writer, 1784). The structure also inspired the future of bridge design and engineering.[127]

To me, the epitome of the monumental, industrial, iron, wood, and glass building is the Crystal Palace, designed by the renowned gardener Joseph Paxton, and originally built for the Great Exhibition of 1851 in London’s Hyde Park. Although it was immediately acclaimed for its modern architecture, only two years later the building was dismantled and reassembled in Sydenham.

Public Domain: The Crystal Palace in Hyde Park for Grand International Exhibition of 1851 - The Crystal Palace - Wikipedia

In this small oil painting, though, Camille Pissarro relegated what was considered the world’s largest building to the left side of the canvas, as if to give equal space to the “modern-life” scene of families and carriages parading by Sydenham’s more recently constructed middle-class homes:

The Crystal Palace (1871), by Camille Pissarro (French, 1830–1903)[128]

[127] See: History of Iron Bridge | English Heritage (english-heritage.org.uk)

[128] Public Domain: The Crystal Palace | The Art Institute of Chicago (artic.edu)

The impact of the Industrial Revolution on 19th-century art is a fascinating subject of study, well beyond the scope of this research paper. However, the few examples above, focusing on some scientific advances in architecture, engineering and industry, show how some painters documented and responded to the profound transformations of their time. Though their art often celebrates industrial progress, it is also a way to reflect and critique the new world taking shape.
Indeed, many artists used their work to comment on the social impact of industrialization, highlighting issues like child labour, poverty, and the exploitation of workers: from Turner's subtle painting *Keelmen Heaving in Coals by Moonlight* (see below) to Henry Wallis's *The Stonebreaker* (see above, p. 55), many artists used their art to advocate for social change.

Keelmen Heaving in Coals by Moonlight (1835), J. M. W. Turner, National Gallery, London

> The setting is the port of Newcastle, England. To the right, the keelmen and the dark, flat–bottomed keels that carried the coal from Northumberland and Durham down the River Tyne are silhouetted against the orange and white flames from the torches, as the coal is transferred to the sailing ships. Coal was used to fuel the factories, mills, railroads, steamships, and other great machines that were transforming Britain during the Industrial Revolution. *The dark smoke rising on the right may refer to the increasing air pollution.* Here Turner brings the great force of his romantic genius to *a common scene of working-class men at hard labour.* Although *the subject of the painting is rooted in the grim realities of the industrial revolution*, in Turner's hands it transcends the specifics of time and place and becomes an image of startling visual poetry. [129] (*my emphasis*)

[129] Picture and caption: [Keelmen Heaving in Coals by Moonlight (nga.gov)]

3.2 The atom: from chemistry to physics

We saw that the notion of "atoms" had been introduced in antiquity (see p.6) then inspired Descartes's mechanist philosophy (see p.34). However, it is only in the 19th century that John Dalton (1766-1844) gave this term the modern sense we still know today. A leading light in Manchester's scientific life, he did some important experimental work on chemistry. Scientists had already found regularities when chemicals react with each other. In 1803, Dalton formulated a law of multiple proportions. These observed regularities suggested the idea that elements are in fact atoms, which combine with other atoms in simple whole-number ratios to form chemical compounds. He published his theory in *New System of Chemical Philosophy* (1808), which would provide the foundations of modern chemistry in the early 19th century. In 1811, the Italian physicist Amadeo Avogadro (1776-1856) adhering to this atomic theory, demonstrated that all gases, submitted to the same conditions, are composed of a fix number of molecules. This result would be confirmed three years later by the works of the French scientist André Marie Ampère (see p.49). In the late 1860s, researching a law underlying the diversity and number of elements led the Russian scientist Dmitry Mendeleev (1834-1907) to formulate a table classifying elements by their atomic weight. This 'periodic table' (as it still known today) outlined the periodicity of characteristic chemical properties, common to several elements, thus allowing to predict the existence and properties of substances which had not been discovered then. In the following decades, chemists discovered several elements to fill the gaps in that table. They investigated the structure of molecules and started to build 3D-models with little balls representing atoms and sticks for chemical bonds. Not only did these models have educational purposes, but they also facilitated research on isomers, i.e. compounds that contain the same number of atoms of the same elements but differ in structural arrangement and properties. However, it is only at the beginning of the 20th century that physicists would develop indirect methods to confirm the existence of atoms.

Humphry Davy, a scientist and a poet.[130]

Among the chemists who paved the way for this cutting-edge science in the early 19th century, I would like to focus now on the flamboyant and socially ambitious Humphry Davy (1778-1829), because his legacy—his notebooks in particular—is a fascinating example of the intertwined history of arts and sciences in Britain. Though he is usually remembered as the inventor of a revolutionary miner's safety lamp, his wild popularity came as much from his influence on popular culture as it did from his contributions to chemistry and applied science.

Coming from a Cornwall working-class background, he was apprenticed to a local surgeon and never went to university. But his appetite for knowledge was noticed by two visiting convalescents with scientific and industrial backgrounds, Gregory Watt and Tom Wedgwood. In 1798, on their recommendation, Davy was appointed as assistant to the new Medical Pneumatic Institution (MPI) in Bristol. Davy's inquiring mind was shaped by the radical intellectual circles he encountered at the MPI, where he met other inquirers into nature, including the Lake poets—Coleridge, Southey, and

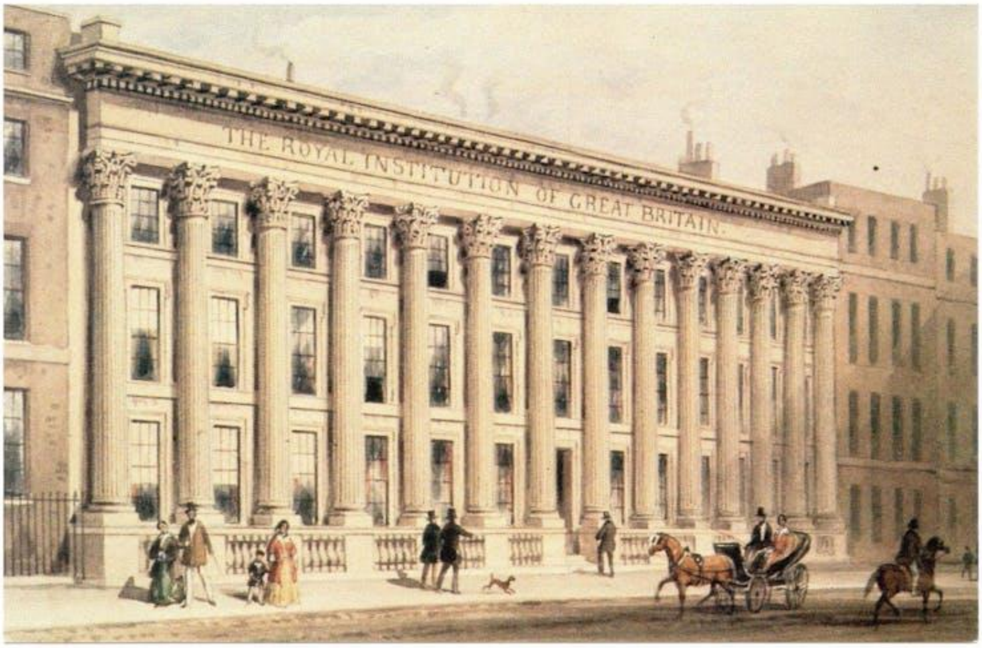
[130] For this part, I am particularly indebted to Lancaster University's MOOC, *Humphry Davy: Laughing Gas, Literature, and the Lamp.*

Wordsworth—for whom experiment and poetry were related ways of exploring man's relationship to the world. Davy's guiding principles of genius, power, sublimity, and nature were developed at this time.

The most promising discovery of the Bristol years was nitrous oxide, the wonder working gas. Davy and his friends trialled its effects—mental and physical exhilaration—on themselves. It heightened and lightened consciousness, conducing to poetic visions of nature.[131] But Davy ultimately showed it did not cure diseases: the PMI had not found a revolutionary cure for consumption. In 1801, Davy left that institution, remodelled himself under the patronage of Sir Joseph Banks, the President of the Royal Society, and began his meteoric rise to fame.

Moving to London, Davy eventually became director of the Royal Institution's programme of chemical research and, later, President of the Royal Society. He shed his radicalism and became an establishment man, associating with lords and ladies as well as fellow men of science. He used these associations to get support for his research, raising funds to build the largest voltaic pile (see p.49) in existence, in the laboratory of the Royal Institution.[132] Wielding this new technology, he used electricity to break substances apart and reveal unknown elements. He isolated sodium, potassium, barium, strontium, calcium, boron, and magnesium. He overthrew the oxygen-based chemical theory then in vogue by showing chlorine's elementary status, achievements that led him to be hailed as the greatest chemist that has ever lived.

In the first few years of the 19th century, there was no hotter spectacle in London than Davy's lectures at the Royal Institution. Hundreds of members of the public, many of them women, crowded into the lecture theatre to hear the charismatic Davy speak about his cutting-edge research. They would watch demonstrations of his work, which often included elaborate explosions and other breathtaking displays: people went often to lectures for fun as much as to learn.



The Royal Institution by Thomas Hosmer Shepherd (c. 1838) [133]

[131] See the article: https://wellcomecollection.org/articles/YxnTCBEAACEAnk2Y

[132] Founded in 1799 by the leading British scientists of the age, the Royal Institution is an organisation for scientific education and research. Its Royal Charter was granted in 1800.

[133] Public Domain: File:Royal Institution Shepherd TH.jpg - Wikipedia

Lord Byron (1788-1824) had met Humphry Davy in London before he left England for Italy in 1816. In *Don Juan*, Canto I (1818), stanzas 128-132 refer to recent inventions, in a way typical of Byron's scientific dilettantism: "although he reveals his customary scepticism of the importance of scientific discoveries, he was proud of keeping up with what took place outside the narrow world of litterateur." [134]

> Man's a strange animal and makes strange use
> Of his own nature and the various arts,
> And likes particularly to produce
> Some new experiment to show his part. (I, 128, 1-4)
>
> And galvanism has set some corpses grinning… (I, 130,2) See § 2.5, p.49
>
> This is the patent age of new inventions
> For killing bodies and for saving souls,
> All propagated with the best intentions.
> Sir Humphry Davy's lantern, by which coals
> Are safely mined for in the mode he mentions,
> Timbuctoo travels, voyages to the poles
> Are ways to benefit mankind, as true
> Perhaps as shooting them at Waterloo. (I, 132, 1-8)

As Swift had caricatured the Royal Society in *Gulliver's Travels* fifty years before (see p. 37), the Royal Institution's lectures were satirized in cartoons, such as the following one, produced by James Gillray (1756-1815), a British caricaturist and printmaker famous for his etched political and social satires.

[134] Lord Byron, *Don Juan*, note p. 580

The etching above[135] depicts a lecture entitled 'New Discoveries in Pneumatics' given in 1802 at the newly founded Royal Institution. It shows a lecturer giving laughing gas to Sir John Hippisley, with unfortunate results. Assisting the lecturer is an impish Humphry Davy, who manipulates the gas bags behind the bench. On the lecture table, instruments (air-pumps, receivers and pneumatic toys) are displayed. The audience contains several famous people of the day.[136]

The first lecture Davy gave at the Royal Institution was about galvanism (see § 2.5, p.49). The force was thought at the time to be capable of animating matter, or of bringing something dead to life. In his work *A Discourse, Introductory to a Course of Lectures Delivered in the Royal Institution*[137], we read the following passages:

> 'Science has given to [man] an acquaintance with the different relations of the parts of the external world; and more than that, it has bestowed upon him powers which may be almost called creative; which have enabled him to modify and change the beings surrounding him, and by his experiments to interrogate nature with power, not simply as a scholar, passive and seeking only to understand her operations, but rather as a master, active with his own instruments.' (Discourse, p. 319)
>
> 'Science has done much for man, but it is capable of doing still more; its sources of improvement are not yet exhausted; the benefits that it has conferred ought to excite our hopes of its capability of conferring new benefits; and, in considering the progressiveness of our nature, we may reasonably look forwards to a state of greater cultivation and happiness than that which we at present enjoy.' (Discourse, p. 319)
>
> '[The alchemists'] views of things have passed away, and a new science has gradually arisen. The dim and uncertain twilight of discovery, which gave to objects false or indefinite appearances, has been succeeded by the steady light of truth, which has shown the external world in its distinct forms, and in its true relations to human powers. The composition of the atmosphere, and the properties of the gases, have been ascertained; the phenomena of electricity have been developed; the lightnings have been taken from the clouds; and, lastly, a new influence has been discovered, which has enabled man to produce from combinations of dead matter effects which were formerly occasioned only by animal organs.' (Discourse, p. 321)

In 1978, Laura E. Crouch published an article[138] drawing attention to the similarities between Davy's *A Discourse* and Mary Shelley's novel *Frankenstein*, which was first published in 1818.[139] Since then, many critics have agreed that Davy seems to be a model for Frankenstein's tutor Professor Waldman, if not for Victor Frankenstein himself. Indeed, we find several echoes of the *Discourse* extracts and of Davy's short biography above into the following passages from *Frankenstein*:

> [M. Waldman] began his lecture by a recapitulation of the history of chemistry, and the various improvements made by different men of learning, pronouncing with fervour the names of the most distinguished discoverers. He then took a cursory view of the present state of the science, and explained many of its elementary terms. After having made a few preparatory experiments, he concluded with a panegyric upon modern chemistry, the terms of which I shall never forget: –

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[135] Source: https://www.mhs.ox.ac.uk/exhibits/in-print-exhibit/print-caricature/

[136] Source: New Discoveries in Pneumaticks | Royal Institution (rigb.org)

[137] See the full text on: The Collected Works of Sir Humphry Davy ...: Early miscellaneous papers from ... - Sir Humphry Davy - Google Livres

[138] See Laura Crouch's article: Crouch, "Davy's Discourse" (upenn.edu)

[139] Mary Shelley, *Frankenstein*, Penguin Classics, edited by Maurice Hindle.

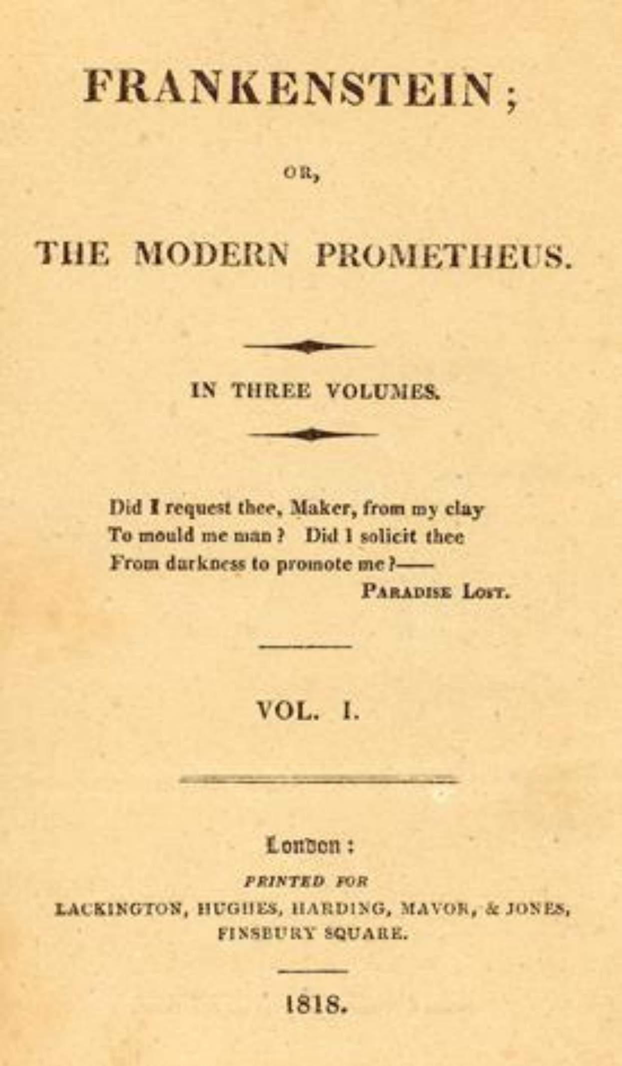
> "The ancient teachers of this science," said he, "promised impossibilities, and performed nothing. The modern masters promise very little; they know that metals cannot be transmuted, and that the elixir of life is a chimera. But these philosophers, whose hands seem only made to dabble in dirt, and their eyes to pore over the microscope or crucible, have indeed performed miracles. They penetrate into the recesses of nature, and shew how she works in her hiding places. They ascend into the heavens; they have discovered how the blood circulates, and the nature of the air we breathe. They have acquired new and almost unlimited powers; they can command the thunders of heaven, mimic the earthquake, and even mock the invisible world with its own shadows."
> … and soon my mind was filled with one thought, one conception, one purpose. So much has been done, exclaimed the soul of Frankenstein,—more far more will I achieve: trading in the steps already marked, I will pioneer a new way, explore unknown powers, and unfold to the world the deepest mysteries of creation. (*Frankenstein*, pp. 48-49)
> None but those who have experienced them can conceive of the enticements of science. In other studies you go as far as others have gone before you, and there is nothing more to know; but in a scientific pursuit there is continual food for discovery and wonder. A mind of moderate capacity, which closely pursues one study, must infallibly arrive at great proficiency in that study; and I, who continually sought the attainment of one object of pursuit, and was solely wrapped up in this, improved so rapidly, that, at the end of two years, I made some discoveries in the improvement of some chemical instruments, which procured me great esteem and admiration at the university. (*Frankenstein*, pp. 51-52)

Davy had been a visitor to the Godwin household in Mary's childhood[140], and she was reading his works *Elements of Chemical Philosophy* (1812) and *A Discourse* in October and November 1816. Moreover, in the Author's Introduction to *Frankenstein* (p. 8), Mary wrote that during one of the conversations between Lord Byron and Shelley, "they talked of the experiments of Dr Darwin… Perhaps a corpse would be re-animated; galvanism had given token of such things: perhaps the component parts of a creature might be manufactured, brought together, and endued with vital warmth."

In his youth, the poet and philosopher Percy Bysshe Shelley (1792-1822) had bought and experimented with chemical apparatus and materials and read 'treatises on magic and witchcraft, as well as those more modern ones detailing the miracles of electricity and galvanism.'[141] He admired both Humphry Davy and Erasmus Darwin (see § 2.4, p. 47). He referred to the latter in the first sentence of his preface to the novel: "The event on which this fiction is founded, has been supposed, by Dr Darwin, and some of the physiological writers of Germany, as not of impossible occurrence" (*Frankenstein*, p. 11).

However, from the 1831 edition, Mary made additions to the creature's speeches, in which scientists are demonized. "As a cautionary tale warning of the dangers that can be cast into society by a presuming experimental science, *Frankenstein* is without equal. Mary Shelley's cleverly inspired theme of an uncontrollable creature wreaking vengeful destruction upon the heads of his monomaniacal scientific Creator and his world is sustained in a way that makes the book a powerfully unique presence in English literature" (Maurice Hindle, Introduction to *Frankenstein*, p. xi).

[140] Mary Shelley was born Mary Wollstonecraft Godwin in London, in 1797, and died in London in 1851.
[141] Preface to Mary Shelley's *Frankenstein* by Maurice Hindle, p. xxv.



FRANKENSTEIN;

OR,

THE MODERN PROMETHEUS.

IN THREE VOLUMES.

Did I request thee, Maker, from my clay
To mould me man? Did I solicit thee
From darkness to promote me?——
PARADISE LOST.

VOL. I.

London:
PRINTED FOR
LACKINGTON, HUGHES, HARDING, MAVOR, & JONES,
FINSBURY SQUARE.

1818.

The first edition of *Frankenstein* was published anonymously in 1818.

The frontispiece of the 1831 edition of *Frankenstein*. [142]

Let's now come back to Davy's multifaceted legacy, and especially to his little-known poetry, closely related to his research work as a chemist, as a popular lecturer, and as an early philosopher of Romantic science. Be they praised by Coleridge, or regarded as the work of a talented amateur whose serious interests lay elsewhere, Davy's poems are useful as a continuous guide to his intellectual development. One of the attractions of Davy for William Wordsworth (1770-1850) and Samuel Taylor Coleridge (1872-1834) was the wide-ranging character of his intellectual interests.[143]

According to Professor Richard Holmes[144], Davy's early poems reflect his enthusiasm for the outdoor life, fishing—which remained a passion all his life—shooting, riding and sketching the landscape of his native region, Cornwall. They also witness his fascination with scientific books, experiments, storytelling, and speculative ideas. In 'The Sons of Genius' he expressed his ambition to become a great scientist like Sir Isaac Newton, and on "Newtonian wings sublime to soar / Through the bright regions of the starry sky."

[142] Illustrations from Verso, the blog of the Huntington Library: "Frankenstein" Then and Now | The Huntington
[143] For a detailed study of Davy's poetry, read the following articles: J. Z. Fullmer, 'The Poetry of Sir Humphry Davy' and Roger Sharrock, 'The Chemist and the Poet: Sir Humphry Davy and the Preface to Lyrical Ballads'.
[144] Lancaster University, *Humphry Davy: Laughing Gas, Literature, and the Lamp*, MOOC steps 2.2 and 4.5.

In 1798, when Davy moved to Bristol, he formed close friendship with Robert Southey (1774-1843)—who would publish six of Davy's Cornish poems in the 1799 Bristol *Annual Anthology*—and Coleridge, who encouraged him to write a long philosophical poem about the nature of life, and whether he had a religious or an atheist view of it. Davy had many letter exchanges with Southey and Coleridge on the connections between scientific and poetic observation. Coleridge wrote that science being necessarily performed with the passion of hope, it is poetical. Davy, making his scientific notes out of doors, deliberately cultivated a deep sympathy with nature. Yet, he also remarked "how different is the idea of life in a physiologist and a poet."
When Davy gave lectures at the Royal Institution, some visitors noted that they were frequently "figurative and poetical". While Coleridge attended them to "enlarge [his] stock of metaphors", Davy brought him to lecture on poetry and the imagination.

Through Coleridge, Davy also met William Wordsworth. He greatly admired him and helped prepare the second edition of *Lyrical Ballads* for the press. Davy's own influence on Wordsworth appears in the preface to this 1800 edition. Though Wordsworth places poetry at the heart of all knowledge, he declares that the poet 'will be ready to follow the steps of the man of science' if or when the time comes. (Note: the term 'scientist' would only be coined in 1833 as an analogy to 'artist.')

> …Poetry is the most philosophic of all writing… its object is truth, not individual and local, but general, and operative… Poetry is the image of man and nature… The Poet writes under one restriction only, namely, the necessity of giving immediate pleasure to a human Being possessed of that information which may be expected from him, not as a lawyer, a physician, a mariner, an astronomer, or a natural philosopher, but as a Man. Except this one restriction, there is no object standing between the Poet and the image of things; between this, and the Biographer and Historian, there are a thousand.
> We have no knowledge, that is, no general principles drawn from the contemplation of particular facts, but what has been built up by pleasure, and exists in us by pleasure alone. The Man of science, the Chemist and Mathematician, whatever difficulties and disgusts they may have had to struggle with, know and feel this. …
> The knowledge both of the Poet and the Man of science is pleasure; but the knowledge of the one cleaves to us as a necessary part of our existence, our natural and unalienable inheritance; the other is a personal and individual acquisition, slow to come to us, and by no habitual and direct sympathy connecting us with our fellow-beings. The Man of science seeks truth as a remote and unknown benefactor; he cherishes and loves it in his solitude: the Poet, singing a song in which all human beings join with him, rejoices in the presence of truth as our visible friend and hourly companion. Poetry is the breath and finer spirit of all knowledge; it is the impassioned expression which is in the countenance of all Science….
> Poetry is the first and last of all knowledge—it is as immortal as the heart of man. If the labours of Men of science should ever create any material revolution, direct or indirect, in our condition, and in the impressions which we habitually receive, **the Poet will sleep then no more than at present; he will be ready to follow the steps of the Man of science**, not only in those general indirect effects, but he will be at his side, carrying sensation into the midst of the objects of the science itself. **The remotest discoveries of the Chemist, the Botanist, or Mineralogist, will be as proper objects of the Poet's art as any upon which it can be employed**, if the time should ever come when these things shall be familiar to us, and the relations under which they are contemplated by the followers of these respective sciences shall be manifestly and palpably material to us as enjoying and suffering beings. If the time should ever come when what is now called science, thus familiarized to men, shall be ready

> to put on, as it were, a form of flesh and blood, the Poet will lend his divine spirit to aid the transfiguration, and will welcome the Being thus produced, as a dear and genuine inmate of the household of man...[145] (my emphasis)

After a nearly fatal illness brought on by overwork, Davy had the time to reflect on his experience in the laboratory. In a complex, philosophical poem beginning 'Lo, o'er the earth the kindling spirit pours', Davy reflects on the continuous transformations in the physical universe. He asked whether mankind shares in this transience or intellectually transcends it, and perhaps, spiritually evolves. From Coleridge, Davy drew the image of nature as an Aeolian harp played upon by some unnamed higher power, the one intelligence.

Davy then reflected on the overall purpose of science, and the possibilities of it benefiting humanity on a new scale. In 'The Massy Pillars of the Earth' (See Appendix 2), he developed his previous idea of transformations, suggesting that science shows that nothing is ever really destroyed in the physical universe. This promises a kind of immortality for man. If matter cannot be destroyed, the living mind can never die.

When he became President of the Royal Society in 1820,[146] Davy used the prestige of the role and his connections with government to put science on an institutional basis. In 1823-4, he helped found the Zoological Society, and gain land for its menagerie. He campaigned to make the British Museum take its natural history collections more seriously, and helped gain extra staff at the Royal Observatory, Greenwich, to carry out its observations of the night skies. And he founded the Athenaeum Club, as a venue where men of literature and men of science could meet.

However, from the mid-1820s, personal and professional setbacks made Davy irritable and high-handed; criticized by radical newspapers, he became defensive and bitter.

His reputation also suffered when he opposed the election of Michael Faraday (see p. 69), his brilliant assistant, as a Fellow, holding a grudge because he felt Faraday had claimed for himself a discovery stemming from Davy's own work. To the younger generation, Davy now seemed a jealous autocrat.

After a major stroke in December 1826, he was forced to give up his professional life and spent much of the two following years travelling in Europe, trying to recover his health. Again, he conveyed his love of nature in *Salmonia* (1828), a book about the pleasures of angling, and *Consolations in Travel* —a book full of a Romantic engagement with the spiritual through the natural world—published posthumously in 1830. After his death in 1829, Davy's brother tried to secure his reputation by publishing a biography and editing his Collected Works. [147]

[145] Text of the 1800 preface available on this link: https://www.bartleby.com/lit-hub/hc/prefaces-and-prologues/105903/

[146] See: Davy's vaulting ambition | Royal Society

[147] Professor Tim Fulford, Lancaster University, MOOC *Humphry Davy*, step 4.1.

3.3 Electromagnetism

In 1820, the Danish physicist Hans Christian Oersted (1777-1851) discovered electromagnetism, i.e. that an electrical current influences a compass, thus creates a magnetic attraction.
Michael Faraday (1791-1867) was born into an ordinary family and only received a basic education. He spent his youth learning bookbinding, but he discovered science and spent his spare time reading anything he could find about it. He became Davy's assistant at the Royal Institution, where he spent the rest of his professional life. When Oersted's electromagnetism created a wave of scientific interest, Faraday took up the challenge. In September 1821, he devised one of the most famous experiments in scientific history, showing that electrical energy could be converted into mechanical energy, thus inventing the principal of the electrical motor. The notions of 'fields' and 'lines of force' in electricity and magnetism, defined intuitively by Faraday, and made visible by the distribution of iron dust between the poles of a magnet, would be formulated into a mathematical theory by James Clerck Maxwell (1831-1879) in the early 1860s. His equations showed that the electromagnetic fields have wave-like properties, a very important discovery in physics. This wave travels at the speed of light. Maxwell predicted the entire range of waves that we know now. He published the synthesis of his work in *Treatise on Electricity and Magnetism* (1873). In the mid-1880s, the German physicist Heinrich Rudolph Hertz (1857-1894) would produce and detect the waves anticipated by Maxwell. The importance of these "Hertzian" waves was quickly understood, and a decade later, the radio was created by the Italian physicist, inventor and businessman, Guglielmo Marconi (1874-1937).
Maxwell is ranked with Sir Isaac Newton and Albert Einstein for the fundamental nature of his contributions. In 1931, on the 100th anniversary of Maxwell's birth, Einstein described the change in the conception of reality in physics that resulted from Maxwell's work as "the most profound and the most fruitful that physics has experienced since the time of Newton."[148]

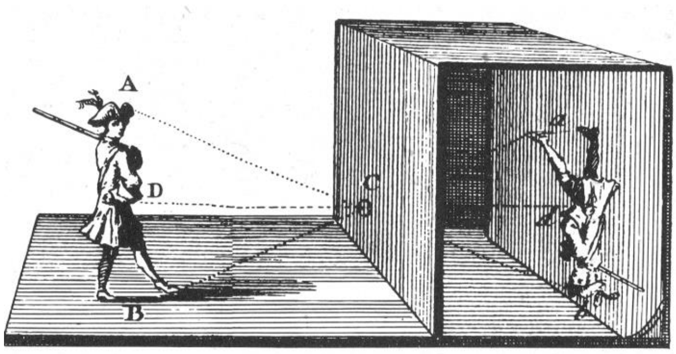
The Old Cavendish Laboratory[149]

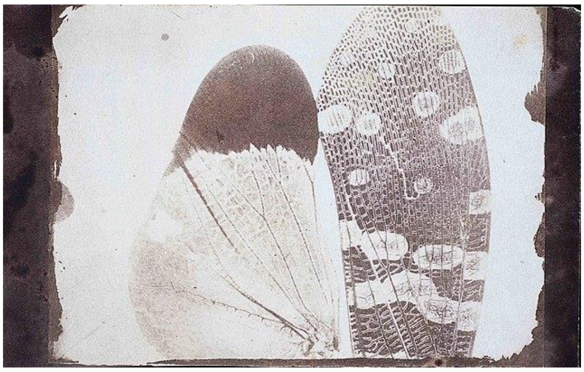
[148] Source: James Clerk Maxwell | Biography & Facts | Britannica
[149] Photo: oldcavendish.jpg | Department of Physics (cam.ac.uk)

By the time he wrote his book, Maxwell had gone to Cambridge to organize the Cavendish Laboratory (see photo above), where so much important physics research would be done in the following decades. He was the first to apply the methods of probability and statistics in describing the properties of an assembly of molecules: he was able to demonstrate that the velocities of molecules in a gas, previously assumed to be equal, must follow a statistical distribution, thus providing the mathematical tools to explain what Robert Boyle and Robert Hooke had observed two centuries before.
Maxwell also investigated optics: he wanted to know why mixing different colours of light produces a different result to mixing the same colours of paint. For example: mixing blue and yellow paint gives green, while mixing blue and yellow light gives pink. He then discovered that colour photographs could be formed using red, green, and blue filters. In 1861, Maxwell presented the world's first colour photograph (of a tartan ribbon).[150]

Photography: from science to art

Born from both principles of the camera obscura image projection (see below) and the discovery that some substances are visibly altered by exposure to light, photography was really developed, through successive inventions, during the 19th century. Between 1826 and 1839, Nicéphore Niepce and Louis Daguerre developed the daguerreotype process, whose technical details were made public in a joined meeting of the Academy of Sciences and the Academy of Fine Arts in Paris. Meanwhile, the competitor approach of paper-based calotype negative and salt print processes invented by William Talbot (1800-77) was already demonstrated in London, but with less publicity.[151]





Talbot allowed free use of the calotype process for scientific applications. He published the first photomicrographs—reminding me of Hooke's *Micrographia*, p. 40—showing a mineral crystal or insect wings (see above) as seen in the "solar microscope"—a method developed for projecting images of tiny objects onto a large screen, using sunlight as a light source. The large projections could then be photographed by exposure to sensitized paper.[152]
Daguerreotyping first became a flourishing industry in the United States, where portraiture became the most popular genre. In the late 1840s every city in the United States had its own "Daguerrean artist," and villages and towns were served by traveling photographers who had fitted up wagons as

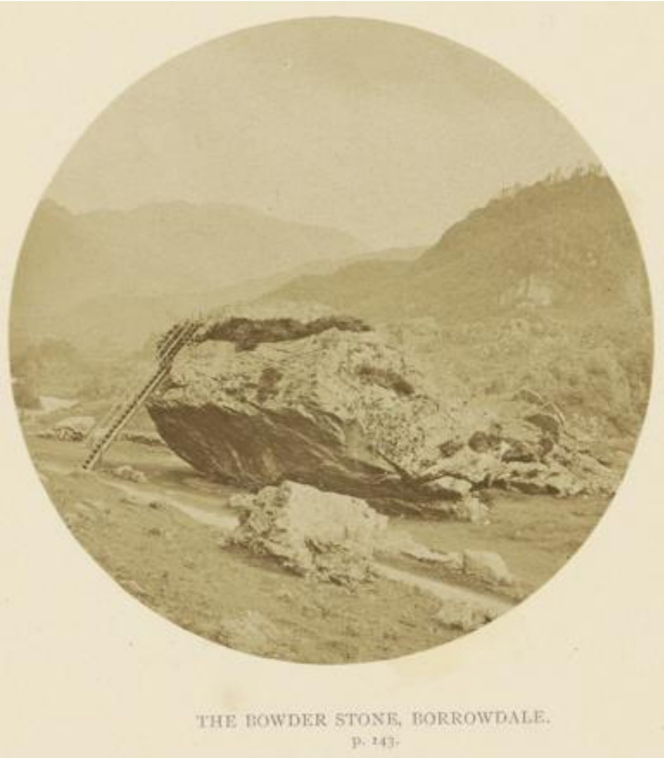
[150] Source: Discoveries - James Clerk Maxwell - Science Hall of Fame - National Library of Scotland (nls.uk)
[151] Drawing of the principle of camera obscura: History of photography - Wikipedia
[152] Text and photo of insect wing: Henry Fox Talbot - Wikipedia

studios. The American success of photographic portraits among all social classes reminds me of the spread of painted portraits among the wealthy middle-classes in 17th-century England.

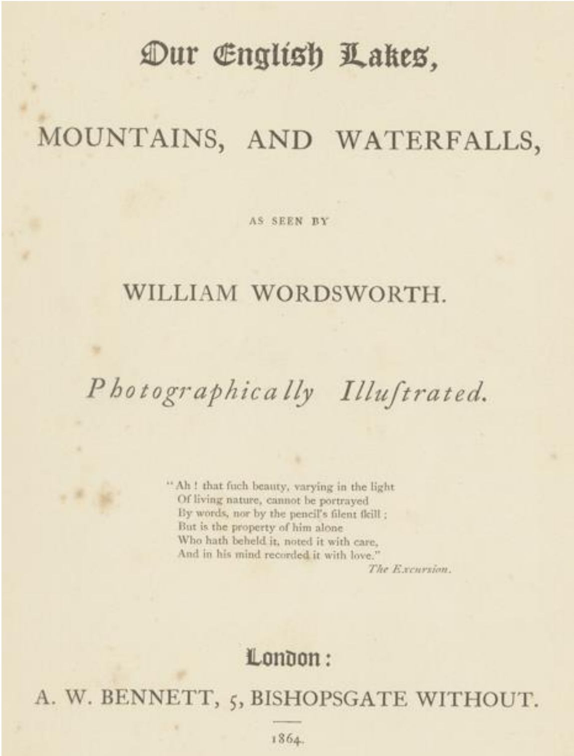
Daguerreotyping spread throughout the world during the 1850s as photographers from England, France, and the United States followed colonialist troops and administrators to the Middle East, Asia, and South America. Army personnel and commercial photographers portrayed foreign dignitaries, landscape, architecture, and monuments in order to show Westerners seemingly exotic cultures.[153]

Many other processes were invented throughout the 19th century in photography, from the calotype to the motion pictures. Though photography history is well beyond the scope of this research paper, it is another striking example of the intertwined history of art and science.

Interestingly, the reciprocal influences between painting and photography are epitomized in the work of some Pre-Raphaelite painters. "The subjects prized by photographers and those appreciated by the Pre-Raphaelites were sometimes similar, including those associated with the literary tastes of the English public and with technological progress, such as the railroad, which made certain remote places accessible".[154] Aurélie Petiot gives the example of the Bowder Stone in Borrowdale, Northwestern England, which had become a tourist spot since the late 18th century and was depicted in one of William Wordsworth's poems. Wordsworth's book, published in 1864, was illustrated with photos, including Thomas Ogle's photography of the Bowder Stone:



The Bowder Stone, Borrowdale, by Thomas Ogle, c. 1854



Our English Lakes,

MOUNTAINS, AND WATERFALLS,

AS SEEN BY

WILLIAM WORDSWORTH.

Photographically Illuſtrated.

"Ah ! that ſuch beauty, varying in the light
Of living nature, cannot be portrayed
By words, nor by the pencil's ſilent ſkill ;
But is the property of him alone
Who hath beheld it, noted it with care,
And in his mind recorded it with love."
The Excursion.

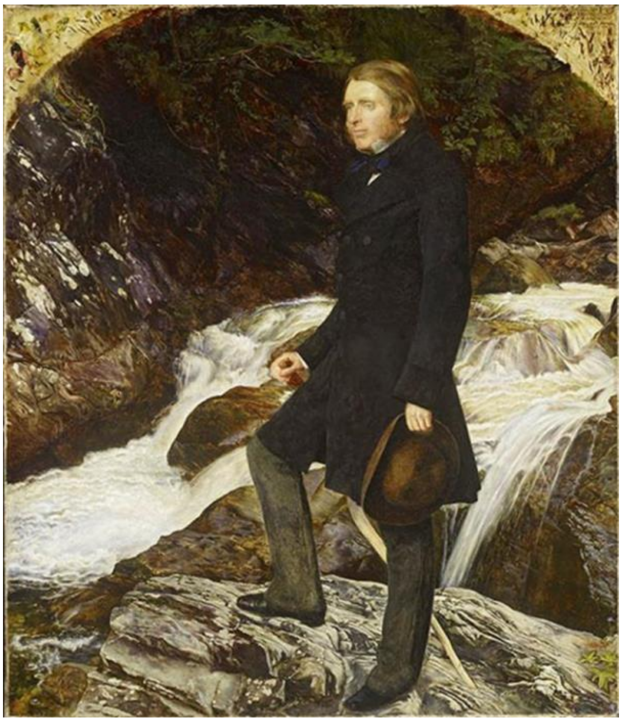
London :
A. W. BENNETT, 5, BISHOPSGATE WITHOUT.
1864.

Title page of Wordsworth's book[155]

The painter John Atkinson Grimshaw (1836-1893), connected to Pre-Raphaelitism, did a painting of the stone, using the same angle of view as in Ogle's photograph. A comparison of the two attests to the geological precision Grimshaw was seeking, comparable to the studies of rocks by Ruskin and Millais, illustrating John Ruskin's principle of "truth to nature" or scientific observation in painting:

[153] Source: History of photography - Early Evolution, Daguerreotype, Film | Britannica
[154] Aurélie Petiot, The Pre-Raphaelites, pp. 103-106.
[155] Both illustrations from: The Bowder Stone, Borrowdale, Thomas Ogle, c. 1854 - in or before 1864 - Rijksmuseum

Bowder Stone, Borrowdale, c.1863–8, by Atkinson Grimshaw. Tate Gallery, London. [156]



Portrait of John Ruskin, by John Everett Millais (1829–96), painted in 1853–54[157]

Study of Gneiss Rock, Glenfinlas, c.1853–54, by John Ruskin (1819–1900)[158]

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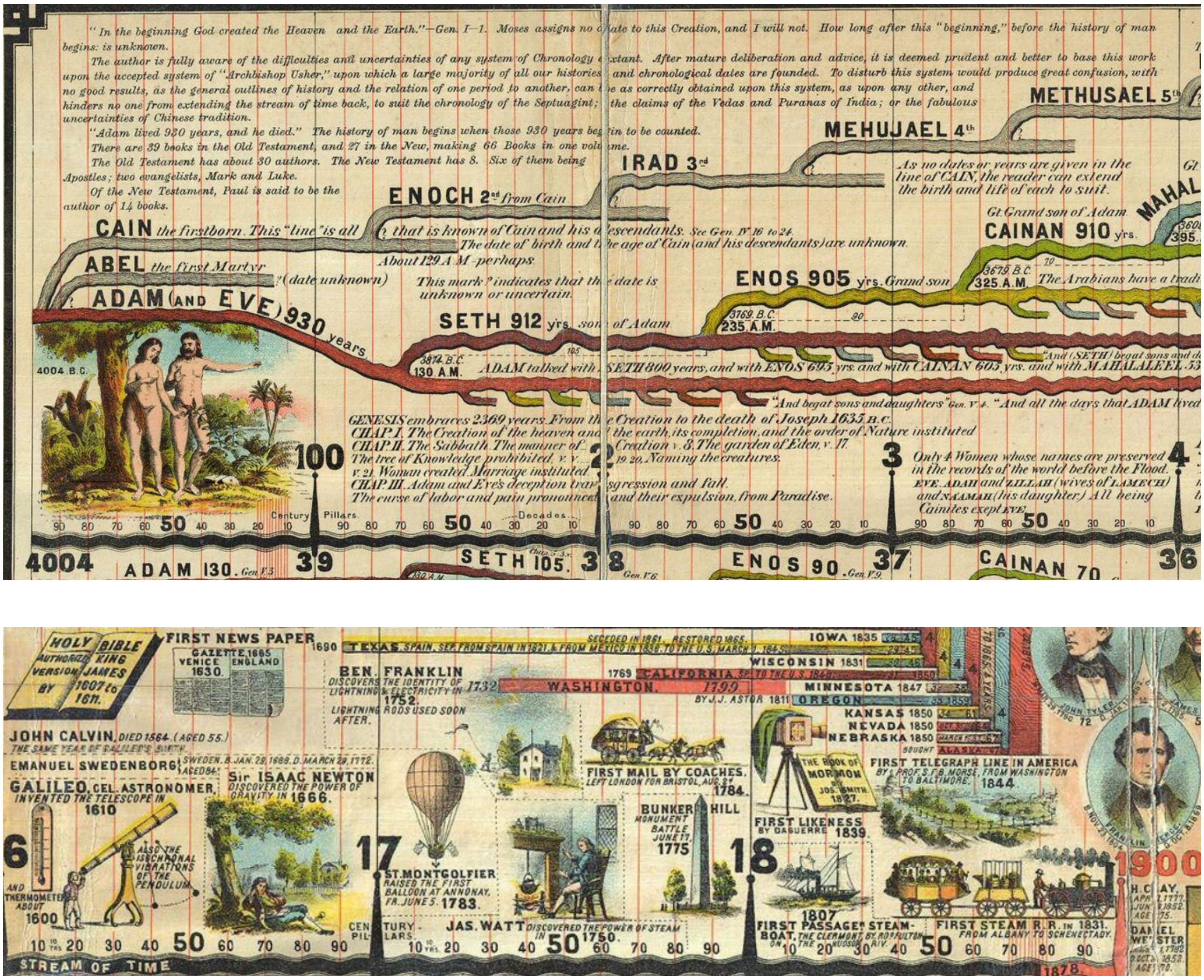
[156]Source: ['Bowder Stone, Borrowdale', Atkinson Grimshaw, c.1863–8 | Tate]

[157] Source: https://www.ashmolean.org/portrait-john-ruskin

[158] Source: http://ruskin.ashmolean.org/collection/8979/object/14350

3.4 From Geology to Geophysics

As a landscape may be dramatically changed by earthquakes or volcanic eruptions, people always wondered about the meaning and causes of these dramatic happenings. Some thought they were supernatural acts, but from the late 1600s, observers began to study the earth as an object of natural history. In the 18th-century, the general thinking about the history of the earth were still dominated by biblical considerations: in the mid-1600s, Archbishop Ussher calculated—according to the Old Testament—that the earth was created in 4004 BC. Though many Christians were already sceptical about Ussher's calculations in the 1650s, Sebastian C. Adams, an American teacher, still attempted to synchronize Biblical history with global historic elements in a gigantic panoramic diagram, intitled *Illustrated Panorama of History* (1871):

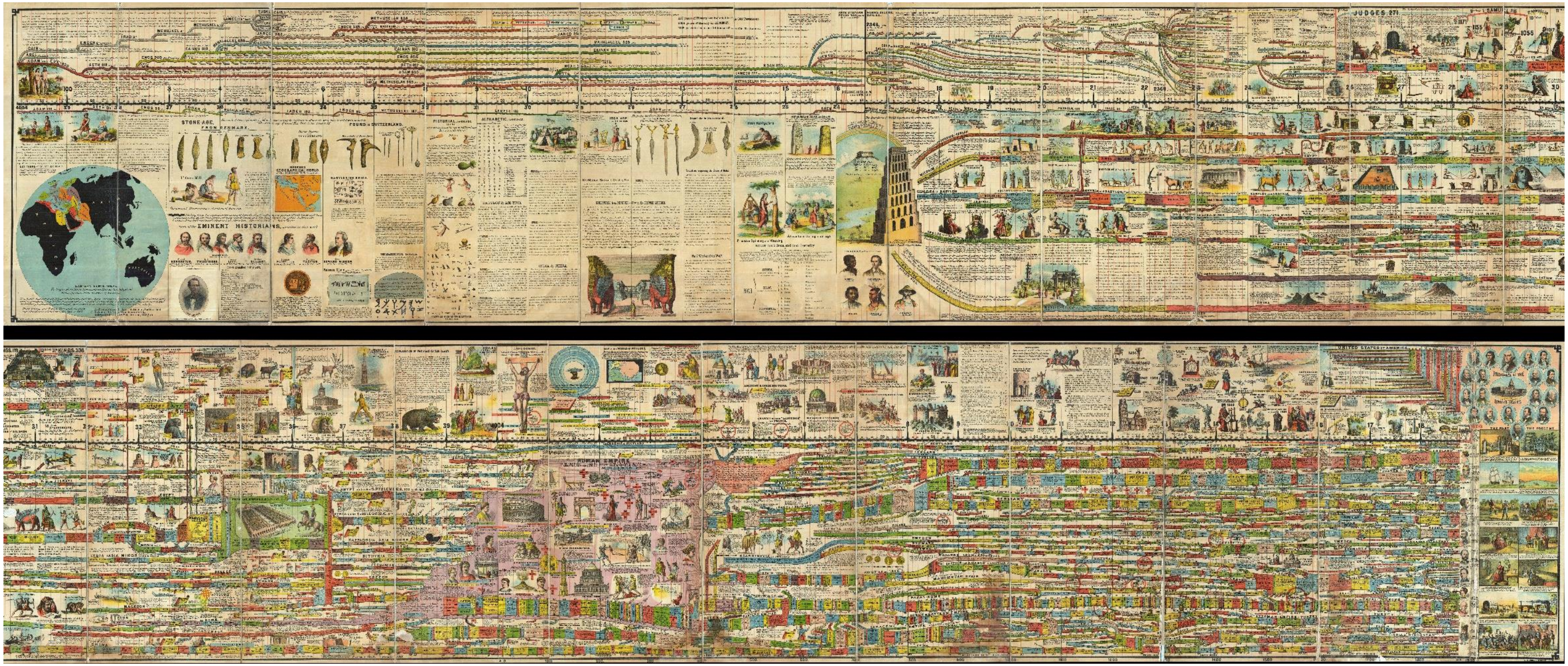


Details of Adams's *Illustrated Panorama of History* (1871) [159]

The whole document is represented next page:

[159] Source: Fichier:1878 Adams Monumental Illustrated Panorama of History - Geographicus - WorldHistory-adams-1871.jpg — Wikipédia (wikipedia.org)

A truly monumental achievement, this *Illustrated Panorama of History* measures 6.6 metres long. It charts the history of the world from a Biblical perspective, starting with the creation of Adam in 4004 B.C. and projecting into the future as far as 1900.



See a detailed view of this work on: Fichier:1878 Adams Monumental Illustrated Panorama of History - Geographicus - WorldHistory-adams-1871.jpg — Wikipédia (wikipedia.org)

From the late 17th century, trying to explain the existence of fossilized shells on mountain tops, far above the present oceans, naturalists began to argue that the world must be older that the few thousand years allowed by Ussher. The Industrial Revolution accelerated the research of coal and minerals useful for the development of industry, thus fostering a fast development of geology: mining deep under the earth helped scientists (like Abraham Werner in Germany and William Smith in Britain) by providing samples of materials not easily obtained on the earth's surface, as well as numerous fossils, different depending on the various layers ('strata') of rocks and earth. Naming and analysing rocks, minerals and fossils allowed the geologists who studied them to start "reading" the earth's history. But two theories split the scientists in the early 19th century.
In the early 1800s, most geologists were 'catastrophists', thinking that the history of earth had been one of periods of stability separated by periods of violent events across the globe. Because the fossils in the layers were generally slightly different, they concluded that the earth history consisted of cataclysmic events–massive floods, violent earthquakes—followed by the creation of new plants and animals that were adapted to the new conditions into being. This scheme fitted with the account of Creation in the Book of Genesis, either by assuming that its six days of creation were actually six long periods, or that the Bible only described the last creation, the age of human beings.

Megaloceros Giganteus

Whitby and Dorset fossils

Sedgwick Museum of Earth Sciences, Cambridge (UK) – Own photos

The French zoologist Georges Cuvier (1769-1832) also argued that the anatomical characteristics distinguishing groups of animals are evidence that species have not changed since the Creation. Each species is so well coordinated, functionally and structurally, that it could not survive significant change. He further maintained that each species was created for its own special purpose and each organ for its special function. Cuvier also applied his views on the correlation of parts to a systematic study of fossils that he had excavated. He coined the word "palaeontology" to give scientists a name for the study of fossils. He reconstructed complete skeletons of unknown fossil quadrupeds, which constituted astonishing new evidence that whole species of animals had become extinct. Furthermore, he discerned a remarkable sequence in the creatures he exhumed. The deeper, more remote strata contained animal remains—giant salamanders, flying reptiles, and extinct elephants—that were far less similar to animals now living than those found in the more recent strata. He summarized his conclusions in 1812 in his *Researches on the Bones of Fossil Vertebrates*, which included the essay "Preliminary Discourse."

In 1830, Charles Lyell (1797-1875) challenged this general account. Lyell wanted to set geologists free to interpret the earth's history without interference with the Church. Inspired by the work of James Hutton (1726-1797), originator of 'uniformitarianism', Lyell explained and developed this view in his *Principles of Geology* (1830-33), i.e., that all features of the Earth's surface are produced by physical, chemical, and biological processes through long periods of geological time. It is only at the beginning of the 20th century that the discovery of radioactivity would give scientists the means to date the various geological strata, and conceive an absolute chronology, based on the disintegration of radioactive elements. However, Lyell's achievements laid the foundations for an understanding of the Earth's development as well as for evolutionary biology: Charles Darwin read Lyell's *Principles of Geology* when he travelled around the globe on the *Beagle* and said that he looked with Lyell's eyes at the geological world. But he came to very different conclusions about what the fossil record actually meant. [160]

Richard Owen (1804-1892) was the man behind the establishment of the Natural History Museum in 1881. He also coined the word 'dinosaurs.' He was the first to recognize them as different from today's reptiles; in 1842 he classified them in a group he called *Dinosauria*. Owen was also noted for his strong opposition to the views of Charles Darwin. He probably influenced the writings of his friend Charles Dickens (1812-1870), one of the great Victorian novelists.

Though serial publication of literary and scientific works was pervasive during the early 19th century, Charles Dickens recognized "suggestive parallels between Owen's particular mode of analyzing petrified fragments and… his own attempts to examine and expose the iniquitous social order that came to dominate later novels". Dickens's journal *Household Words* published an article by Henry Morley, which included a reference to a Megalosaurus in August 16, 1851. The article was called, 'Our Phantom Ship on an Antediluvian Cruise.' A group of travellers meet "*...a land reptile, before which we take the liberty of running. His teeth look too decidedly carnivorous. A sort of crocodile, thirty feet long, with a big body, mounted on high thick legs, is not likely to be friendly with our legs and bodies. Megalosaurus is his name, and, doubtless greedy is his nature.*"

In the opening of *Bleak House* (1852-53), Dickens packed the term 'Megalosaurus' within a metaphor of how unpleasant weather made the streets of London more suitable for prehistoric beasts than Victorians: "It would not be wonderful to meet a Megalosaurus, forty feet long or so, waddling like an elephantine lizard up Holborn Hill." Similarly, in a travelogue from *All the Year Round*, Dickens wondered how subsequent generations might trace child poverty and neglect in the fossils of Victorian London. The prehistoric creatures of Dickens's earlier fiction evolved rapidly into the

[160] William Bynum, *A Little History of Science*, pp. 133-145, and Yves Gingras, *Histoire des Sciences*, pp. 100-102.

“serpents of smoke” and “elephant in a state of melancholy madness” fossilized among the industrialized decay found in *Hard Times* (1854). [161]

When it closed in 1853, the Crystal Palace was taken down and moved to Sydenham Park on the south edge of London (see p.59). As part of the development of the site, the world’s first theme park was created; it was devoted to dinosaurs and other creatures of the prehistoric world. Natural history artist Benjamin Waterhouse Hawkins unveiled his dinosaur sculptures in 1854. These were the world's first full-scale reconstructions of dinosaurs and represented the first three species discovered.

George Baxter's colour print of the Crystal Palace after its move to Sydenham, with some of Benjamin Waterhouse Hawkin's sculptures featured in the foreground [162]

This example illustrates the extraordinary Victorian mix of science, popular culture or entertainment, and business: on 31 December 1853, before the dinosaurs were officially unveiled to the public, Waterhouse Hawkins hosted a banquet to celebrate their launch inviting scientists and officials of the Crystal Palace Company. The dinner took place inside the mould of one of the *Iguanodon* sculptures. [163]

Illustrated books and magazines, such as Louis Figuier’s *La Terre avant le Déluge* (1863) also helped popularize the discoveries of palaeontologists and naturalists for the public.

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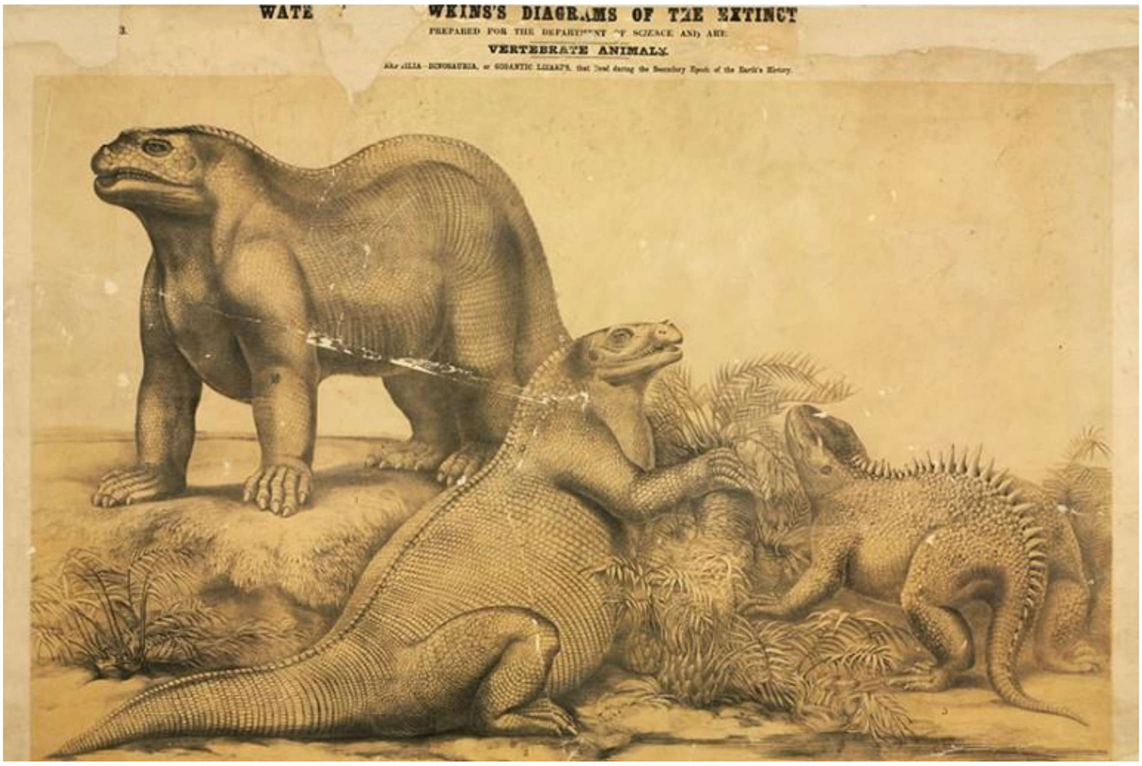
[161] Sources: Charles Dickens and the dinosaurs | OpenLearn - Open University and Charles Dickens and the Dinosaur (charlesdickenspage.com)

[162] Public Domain: Wellcome Collection, CC BY 4.0: c7nzvug2 | Images search | Wellcome Collection

[163] Source: The world's first dinosaur park: what the Victorians got right and wrong | Natural History Museum (nhm.ac.uk)



Benjamin Waterhouse Hawkins's diagrams of *Iguanodon* and *Hylaeosaurus* [164]

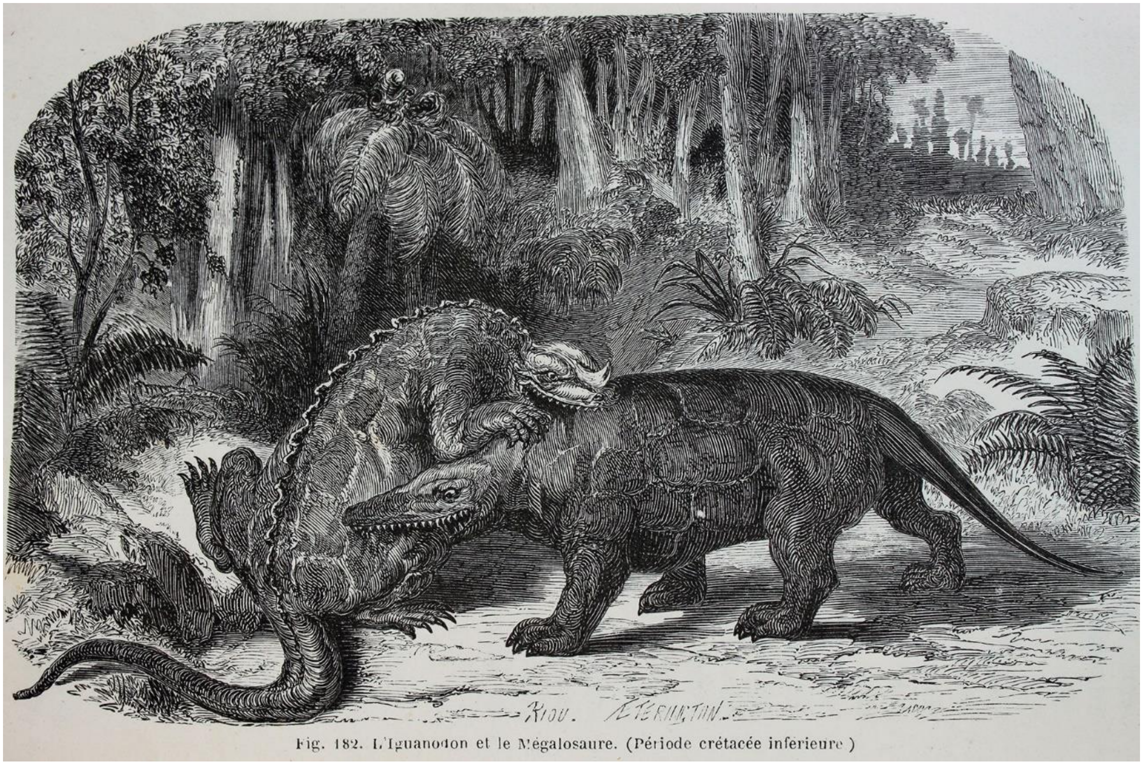


Fig. 182. L'Iguanodon et le Mégalosaure. (Période crétacée inferieure)

Édouard Riou's reconstruction of a battle between *Iguanodon* and *Megalosaurus* featured in Louis Figuier's 1864 book, *La Terre Avant Le Déluge* [165]

[164] Source: The world's first dinosaur park: what the Victorians got right and wrong | Natural History Museum (nhm.ac.uk)

[165]Picture © Fondo Antiguo de la Biblioteca de la Universitaria de Sevilla, via Flickr (CC0 1.0) : 1025108 | "L'Iguanodon et le Mégalosaure". Ilustraciones de ... | Flickr

3.5 Charles Darwin and *The Origin of Species*

Grandson of Erasmus Darwin (see pp. 46-47), Charles Darwin (1809-1882) forged important friendships with his professors of botany and geology at Cambridge University, John Henslow and Adam Sedgwick, who inspired him to become a naturalist. Being offered to become the 'gentleman naturalist' on a surveying voyage aboard the *HMS Beagle* from 1831 to 1836, he collected thousands of specimens and shipped them home, carefully labelled. He was also an outstanding observer of all kinds of natural phenomena: landscapes, people and their customs, and plants, animals and fossils. The circumnavigation of the globe was the making of Charles Darwin. Back home, he had already acquired a scientific reputation through the reports, letters and specimens he had sent back. In 1839, he published his *Journal of Researches* (*The Voyage of the Beagle*), which was immediately popular and remains a classic account of one of the most important scientific journeys ever taken. As Darwin later recalled in his autobiography:

> 'The voyage of the *Beagle* has been by far the most important event in my life and has determined my whole career'. He went on to write:
>
> 'As far as I can judge of myself I worked to the utmost during the voyage from the mere pleasure of investigation, and from my strong desire to add a few facts to the great mass of facts in natural science. But I was also ambitious to take a fair place among scientific men...
>
> …The success of this my first literary child always tickles my vanity more than that of any of my other books. [166]

HMS Beagle in the seaways of Tierra del Fuego, watercolour by the ship's artist Conrad Martens [167]

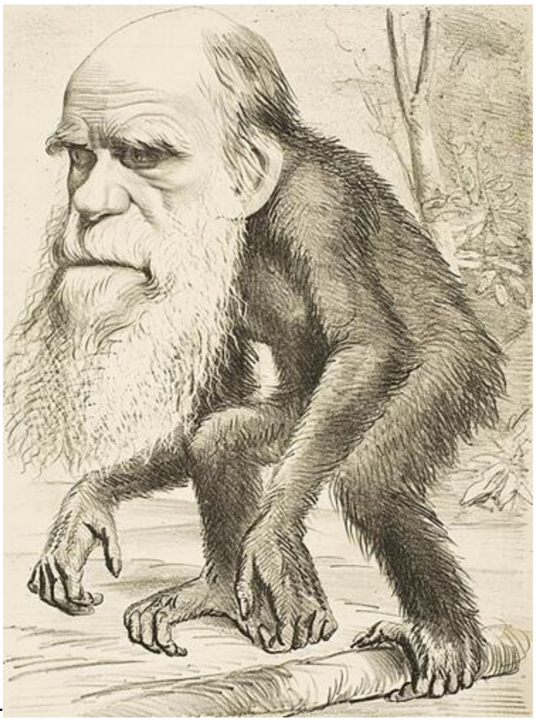
[166] Source: Darwin Online: Journal of Researches (darwin-online.org.uk)

[167] Public Domain: HMS Beagle by Conrad Martens - Charles Darwin - Wikipedia

Inspired by Thomas Malthus's *Essay on the Principle of Population*, Darwin worked out a reason why plants and animals change very gradually over long periods of time, and why some survive when some do not. His proposition that all species of life have descended from a common ancestor is now generally accepted and considered a fundamental scientific concept. In a joint publication with Alfred Russel Wallace (1823-1913), he introduced his scientific theory that this branching pattern of evolution resulted from a process he called natural selection, in which the struggle for existence has a similar effect to the artificial selection involved in selective breeding.

Published in 1859, Darwin's *On the Origin of Species* did for biology what Newton's *Principia* had done for physics. The heart of the book explained how natural selection favours the survival of useful traits—characteristics that help individuals live and reproduce—and produced new species over the long run. The rest of the book was a brilliant demonstration of how well these ideas explained the natural world.

Darwin's theory would have major cultural repercussions, reinforced by the publication of *The Descent of Man* (1871), which dealt directly with the human evolution. Darwin set out evidence from numerous sources that humans are animals, showing continuity of physical and mental attributes, and presented sexual selection to explain human evolution of culture, differences between sexes, and physical and cultural racial classification, while emphasising that humans are all one species. If many people could contemplate the theory of evolution for plants and animals, applying it to human beings conflicted with religious beliefs in God's creation. Recurring fights about this subject would continue even in the 20th century. For instance, in 1925, it was still illegal for teachers to teach human evolution in any state-funded school in the State of Tennessee.[168]



"A Venerable Orang-outang", a caricature of Charles Darwin in *The Hornet* [169]

Caricature of Darwin's theory in the *Punch almanac* for 1882, after the 1881 publication of *The Formation of Vegetable Mould Through the Action of Worms*. [170]

[168]See more detail on Scopes trial - Wikipedia
[169] Public Domain: Editorial cartoon depicting Charles Darwin as an ape (1871) - Charles Darwin - Wikipedia
[170] Public Domain: Man is But a Worm - Charles Darwin - Wikipedia

Elizabeth Gaskell (1810-1865) also was an acclaimed Victorian novelist. In her last novel, *Wives and Daughters*, one of the main characters, Roger Hamley, younger son of the local squire, was inspired by her distant cousin Charles Darwin. According to Karen Boiko,[171]

> In *Wives and Daughters*, Gaskell puts the town of Hollingford under a microscope in order to dramatize both the difficulty and the necessity of classifying people correctly. Gaskell juxtaposes the discourse of natural history and the discourse of social class as she tells the story of Molly Gibson's awakening into adult life in Hollingford and love for Roger Hamley. The trope of classification implicitly connects scientific and social themes of *Wives and Daughters*, which meet in the person of Roger.

Trying to comfort little Molly who had been distressed, Roger brings out his microscope in the evening and shows her 'the treasures he had collected in his morning's ramble.' Then, to 'interest her in his pursuit…he brought out books on the subject, and translated the slightly pompous and technical language into homely everyday speech' (chapter 10, p. 107).
In the story, set in the late 1820s, if Lord Cumnor and Squire Hamley are representatives of a dying feudal age, the positive pattern of change is ushered in by the second generation. Lord Hollingford and Roger Hamley, their respective sons, collaborate in their scientific pursuits.
Gaskell portrays Hollingford as shy and intelligent, part of a European community of scientists and well abreast of development.[172] Roger is portrayed as a keen observer, a naturalist who collects specimens and contributes articles to scientific journals. In Hollingford's letter of recommendation for an award that will support Roger on a discovery voyage to Africa, he enhances Roger's qualities: "much acquired knowledge," "great natural powers of comparison, and classification of facts," "an observer of a fine and accurate kind" (chapter 33, p. 328).

It is worth noting that Gaskell, contrasting the different interests of the two brothers—Osborne the poet and Roger the naturalist—underlines how differently literary and scientific educations at university were still perceived in the 1820s. "It was a great question as to whether [Roger] was to follow his brother to college after he left Rugby. Mrs Hamley thought it would be rather a throwing away of money, as he was so little likely to *distinguish himself in intellectual pursuits*; *anything practical—such as a civil engineer*—would be more the kind of life for him" (p. 38). Although both sons finally study at Cambridge, their parents think that "[Roger] is not likely to have such a brilliant career as Osborne" (p. 58), "Roger is *a scientific sort of a fellow*. Osborne is clever like his mother" (p.61) "Roger knows a deal of natural history, and finds out queer things sometimes…It's a pity *they don't take honours in Natural History at Cambridge*. Roger would be safe enough if they did…. Osborne is a bit of a genius… He'll get a Trinity fellowship, if they play him fair" (pp. 64-65; *my emphasis*). As the Natural Sciences Tripos was only established at Cambridge in 1848, Gaskell stresses in this last sentence the fact that Roger is a man of the future.[173] But behind the evident parents' worship of Osborne, their elder son—the heir of the family—their different perceptions of their sons' interests in life might also reflect the preeminence of the man of letters in 1820s' British society: letters and poetry were still regarded as intellectually superior to science (see Wordsworth's preface to *Lyrical Ballads*, pp. 67-68). That hierarchy would be shaken up later in the 19th century.

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[171] Karen Boiko, 'Reading and (Re)Writing Class: Elizabeth Gaskell's "Wives and Daughters"', p. 86.
[172] Elizabeth Gaskell, *Wives and Daughters*, Wordsworth Classics. Introduction, pp. xi-xii.
[173] *Ibid*, note 23 p. 589.

3.6 From histology to bacteriology

In 1796, an important breakthrough in medicine was made by the English physician Edward Jenner (1749-1823), when he found a process to prevent smallpox: vaccination, which spread worldwide. In 1802 Thomas Jefferson, President of the United States, wrote to Jenner that medicine had 'never before produced any single improvement of such utility… Mankind can never forget that you have lived'. However, vaccination was not popular with everyone. The same year, the Anti-Vaccine Society published the following cartoon by James Gillray, ridiculing Jenner's ideas. People who were fearful of vaccination still used traditional remedies for smallpox, such as applying boiled turnips to the feet.

The Cow-Pock—or—the Wonderful Effects of the New Inoculation! by James Gillray (1802) [174]

But important though Jenner's discovery was, he did not understand precisely why his method worked. No one yet knew that diseases were caused by bacteria and so they continued to rage, unstoppable amid the filth of growing towns.[175]

We saw earlier (§ 2.3, pp. 40-41) that in the 17th and 18th centuries, many people did not trust compound microscopes, because they could produce distortions and chromatic aberrations. From the late 1820s, the technical improvements of microscopes greatly contributed to the development of anatomy and physiology. Xavier Bichat (1771-1802) was among the many scientists who thought using the microscope was not worth the effort. Nonetheless, when he began to investigate the different substances of the human body with a simple magnifying glass, he realized that the same kinds of tissues behaved in similar ways, no matter where they are in the human body. Bichat became the father of 'histology', i.e., the study of cells and tissues.

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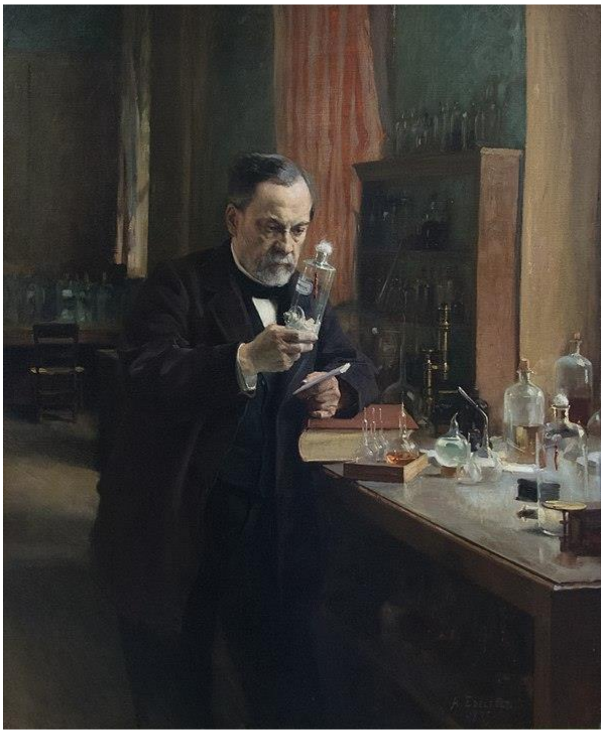
[174] Public Domain: [File:The cow pock.jpg - Wikipedia]
[175] *The History of Britain and Ireland*, pp. 294-295.

In the 1830s, the new microscopes helped two German scientists, Theodor Schwann (1810-1882) and Matthias Jacob Schleiden (1804-1881) to explore how cells were created and worked. They showed that cells were the crucial building-blocks of all vegetal and animal life and paved the way to modern physiology and biology. In the 1850s, Rudolph Virchow (1821-1902) started to apply the cell theory in medicine, for the study of disease, known as pathology. Like Schwann, he saw the cell as the basic unit of living bodies. Understanding their functions in health and disease would be key to a new kind of medicine, based on science. He presented his ideas in *Cellular Pathology* (1858), in which he emphasized that diseases arose, not in organs or tissues in general, but primarily in their individual cells. He showed that cancer growths resulted from cells that were behaving incorrectly and dividing when they should not. Meanwhile, an English botanist, Robert Brown (1773-1858) showed that cells were composed of a *nucleus*, which is darker than the surrounding substance, called *protoplasm*. Scientists quickly accepted the discovery of the nucleus and other parts of cells.

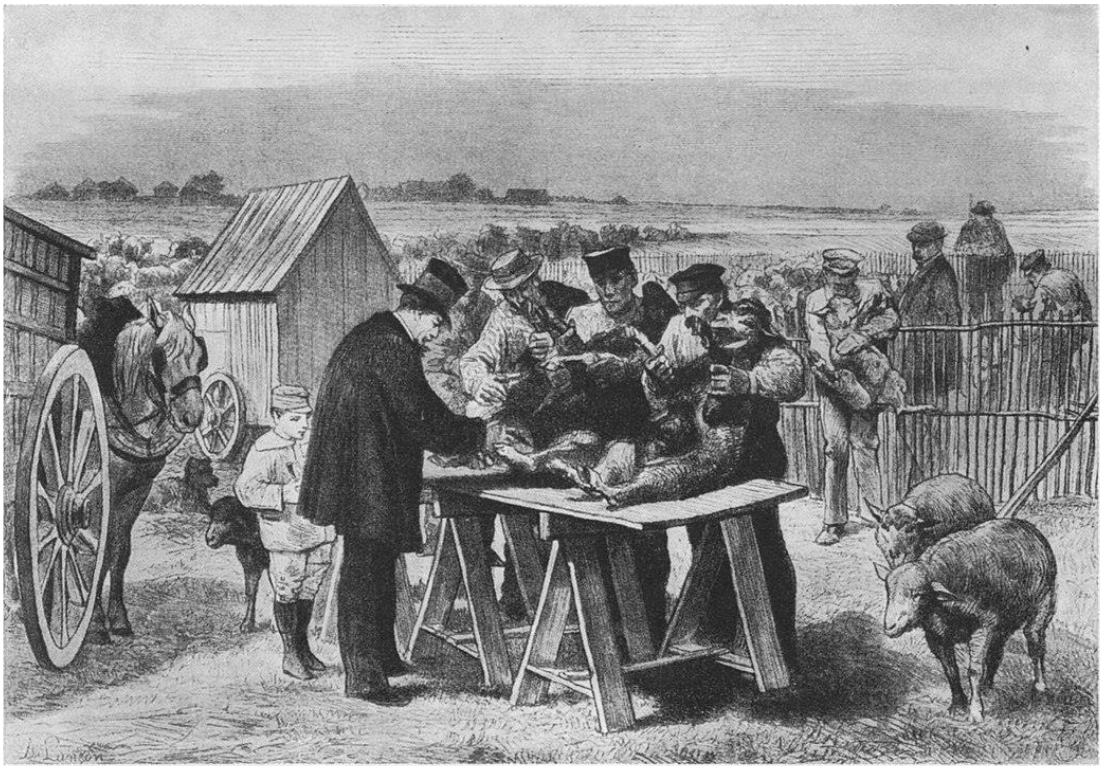


Portrait of Louis Pasteur (1885) by Albert Edelfelt
Musée d'Orsay, Paris [176]

Pasteur's microscope (type Oberhaüser of Nachet)
Musée Pasteur, Paris [177]

Louis Pasteur (1822-1895), a French chemist, was one of the most important founders of medical microbiology. His contributions to science, technology, and medicine are nearly without precedent. Discovering that micro-organisms cause fermentation and disease, he saved the beer, wine, and silk industries in France and originated the process of pasteurization. Inspired by Edward Jenner's new procedure of vaccination discovered in 1796, he also developed vaccines against anthrax and rabies (see illustration next page), caused by micro-organisms, also called germs or bacteria.
Robert Koch (1843-1910), the German rival of Pasteur, was a doctor. He developed strict processes to grow the bacteria and used coloured stains to help identify them. Koch identified the germs that caused two of the most important diseases of the 19th century: tuberculosis and cholera.

[176] Public Domain : File:Portrait de Louis Pasteur Albert Edelfelt.jpg - Wikimedia Commons
[177] Photo licensed under CC BY-SA 4.0 : Microscope Oberhauser de Pasteur - Louis Pasteur — Wikipédia (wikipedia.org)



Pasteur vaccinates sheep against Anthrax at Pouilly-le-Fort, c. 1881, by Auguste André Lançon [178]

Evolution of medical training and practice in the early 19th century

The Anatomy Lesson of Dr Nicolaes Tulp (1632), by Rembrandt, Mauritshuis Museum, The Hague (Netherlands) [179]

[178] Public Domain: File:Louis Pasteur in Pouilly-le-Fort (Illustration - 1881).jpg - Wikimedia Commons
[179] Source: Rembrandt van Rijn The Anatomy Lesson of Dr Nicolaes Tulp | Mauritshuis

Until the Industrial revolution began in 1760, the evolution of surgery was limited by bleeding, infection and pain. From its creation in 1540, the Company of Barber-Surgeons of London (a similar Company was founded in 1505 in Edinburgh) provided services such as bloodletting, dental extractions and lancing abscesses. This company was responsible for teaching and training apprentices, providing licenses for practice and appointing surgeons to the army. The institution came under pressure from the medical profession, and eventually resulted in the formation of a Company of Surgeons in 1745 (in 1722 in Edinburgh), which gained a royal charter in 1800 to become the Royal College of Surgeons. The 1815 Apothecary Act introduced compulsory apprenticeship and formal qualifications for apothecaries—in modern terms general practitioners—under the license of the Society of Apothecaries. It was the beginning of regulation of the medical profession in Britain. The Act required instruction in anatomy, botany, chemistry, *materia medica* and "physic", in addition to six months' practical hospital experience.

Despite this Act, training of medical people in Britain remained disparate: 'The training of a practitioner in Britain in 1830 could vary all the way from classical university study at Oxford and Cambridge (only physicians got the title of Doctor, "Dr") to a series of courses in a provincial hospital to "broom-and-apron apprenticeship in an apothecary's shop."'[180] It was not until the 1830s that students of surgery were required to have obtained a medical degree at a university before commencing studies for membership of the Royal College of Surgeons.[181] This disparity of knowledge, qualifications and abilities between practitioners at the beginning of the 1830s is particularly well rendered in Eliot's novel *Middlemarch*, in which the established doctors and apothecaries of Middlemarch make fresh alliance in order to repel Mr Lydgate, the new, idealist surgeon seen as a priggish interloper(see below, p. 86).

In *Wives and Daughters*, Gaskell consciously writes that unlike his predecessor, "*Mr.* Gibson had become 'the doctor' par excellence at Hollingford" (*my emphasis*). He is a Scottish country surgeon with a "thistly dignity which made every one feel that they must treat him with respect" (p. 33). "[It had been] Mr Gibson's habit…to take two 'pupils' as they were called in the genteel language of Hollingford, 'apprentices' as they were in fact—being bound by indentures, and paying a handsome premium to learn their business." A great deal of apprentices' time was spent preparing pills for the patients, and, according to Dr Gibson, "their mission seemed to be, to be plagued by their master consciously and to plague him unconsciously (*Middlemarch*, p. 28).

Like Gibson's 'pupils', the poet John Keats (1795-1821) was apprenticed in his youth (from 1811 to 1815) to a surgeon and apothecary, Thomas Hammond, at Edmonton, in the north of London. An apothecary was then regarded as a decent and respectable living for a middle-class gentleman with a certain amount of business acumen. When Keats enrolled in October 1815 at Guy's Hospital, the Apothecary Act had just been passed. He was thus one of the very first students to pass the new examinations in July 1816 and become licensed to practice as a surgeon and an apothecary as soon as he would be 21. Consequently, Keats displays an extensive knowledge of botany, and of human pain and death, in his poetry. If his early poetry has sometimes been seen as an escape from the

[180] Source: Apothecaries Act 1815 - Wikipedia
[181] Source: The history of surgery and surgical training in the UK - PMC (nih.gov)

stressful world of Guy's hospital, medical botany, however, offered much to stimulate his imagination. His fascination with beautiful plants that have the power to heal or to poison would be evident through Keats's writing career, from the foxglove bell in 'O solitude' (l. 8) and the 'lush laburnum' in 'I stood tip-toe' (l. 31) to the 'Wolf's bane, tight rooted for its poisonous wine' in 'Ode on Melancholy' (l. 2) and the 'hemlock' in 'Ode to a Nightingale' (l. 2).[182]

Identifying germs not only meant that scientists could make vaccines, and, later, drugs, but it also made modern surgery possible: inspired by Pasteur's germs, Joseph Lister (1827-1912) introduced *antiseptic surgery* as early as 1860s to kill the germs and limit the risks of infection during surgical procedures. Then, Koch invented the autoclave, which sterilized surgical instruments. Koch's *aseptic* surgery would prevent germs getting into the wound in the first place.
"Along with modern hygiene, surgery could not have advanced without anaesthesia. First introduced into medicine in the 1840s, in America, anaesthesia was a triumph for chemistry in the service of medicine, since ether and chloroform were chemicals made in the laboratory."[183]

Eliot's *Middlemarch*: 1830s' British society put under the microscope

Like Gaskell's *Wives and Daughters*, Eliot's novel *Middlemarch*, though published in 1871-2, is set the early 1830s, i.e., between the first Industrial Revolution and the further social and economic developments brought about by the railways throughout Britain. The writer adopts the role of imaginative historian, even scientific investigator, who seeks to analyse recent political and social changes by means of the particular human stories she tells. For my research, however, I will only focus on Eliot's interpretation of how science, classic scholarship and art were perceived in British provincial society during this transition period.

For George Eliot (1819-1880), the profession of medicine was of special importance, and in her novel, she demonstrates her knowledge of 1830s' state-of-the-art in medical practice. One of the main characters is 27-year-old Tertius Lydgate, who arrives in Middlemarch with up-to-the-minute medical knowledge (he is an early user of the stethoscope) and new ideas for medical reform. Lydgate is thus charged by the banker Bulstrode with the management of the future fever hospital, a mission which fills the town's medical establishment with jealousy and resentment.
Eliot refers to the disparity among practitioners in the 1830s, in a caustic dialogue between Bulstrode and Lydgate (*Middlemarch,* pp. 124-125), in which they criticize the backward medical knowledge and skills of the two physicians practising in Middlemarch, as well as the general lack of scientific culture of country practitioners. The novelist also ironically refers to the inadequacy of medical education in Oxford and Cambridge (*Middlemarch,* pp. 145-146) and thus, makes Lydgate complete his medical studies in London, Edinburgh and Paris (see details in Appendix 3).
Lydgate begins his career with the best intentions: Eliot writes of the 'intellectual passion' which grips him while still a boy, when he opens the encyclopaedia at Anatomy and reads of the valves of

[182] Eva Anglessy, *Keats, a Regency Poet* (April 2024), Research Paper pp. 28, 34 and 36: Keats, a Regency poet – The eternal student – anglophile version (eternal-student.com)
[183] William Bynum, A Little History of Science, pp. 154-168.

the heart (*Middlemarch*, p. 144). To him, 'the medical profession as it might be was the finest in the world; presenting the most perfect interchange between science and art' (*Middlemarch,* p. 145). Ambitious and inspired by the scientific discoveries of Jenner and Bichat, he intends to contribute to medical research in finding the 'primitive tissue' in anatomy and make a successful career while staying aloof from the petty politics of Middlemarch (Appendix 3 and *Middlemarch,* pp. 147-9). [184]

As Gaskell contrasted the two brothers' interests (letters and science) in *Wives and Daughters*, Eliot opposes Lydgate, aware of the latest scientific advances in his profession and turned towards the future, to Casaubon, a pedantic, selfish, 45-year-old scholar, turned towards the past, while drawing an ironic parallel between Lydgate's research of the 'primitive tissue' in anatomy, and Casaubon's scholarly research of 'the Key to All Mythologies.' As the latter explains to Dorothea, his future wife, his aim is 'to show… that all the mythical systems or erratic mythical fragments in the world were corruptions of a tradition originally revealed' (*Middlemarch*, p. 24).
However, Will Ladislaw (Casaubon's cousin) explains—using a medical analogy—to a devastated Dorothea that the scholar's research is already obsolete: as he cannot read German, he was not kept informed of foreign research in his field of study. Eliot, through Ladislaw's mouth, also criticizes contemporary English scholarship: 'it is a pity that [Casaubon's labour] should be thrown away, as so much English scholarship is, for want of knowing what is being done by the rest of the world' (see detail in Appendix 3, and *Middlemarch*, pp. 207-8 and 221-2).

Interestingly, in her novel set in the 1830s, Eliot already gave science and classic studies the places they would rather occupy in Victorian society when she wrote *Middlemarch* in the early 1870s: science in the foreground, and traditional scholarship more in the background. Indeed, the declining influence of classical studies in English schools while science was establishing its new place in the modern curriculum would launch a fiery debate in education (see § 3.7 below).

In the microcosm of *Middlemarch*, Eliot also finds a few opportunities to convey some contemporary views about art through the voices of two gentlemen: Ladislaw, an art amateur, and Mr Brooke, Dorothea's uncle, a landowner who certainly made his Grand Tour forty years before and still tries to impress the party with his artistic jargon, when appraising one of Ladislaw's sketches. To Brooke, "this is just the thing for girls—sketching, fine art and so on…" (*Middlemarch* pp. 79-80). Arts (especially drawing and music) were first regarded as attributes to British aristocracy and gentry, but with the development of the middle-classes in the 18th century and of a social hierarchy more based on "taste", artistic activities became part of the education of most wealthy middle-class children, to help them shine in society or climb the social ladder. For instance, Cynthia (Dorethea's sister) and Rosamund (Lydgate's wife) play music to entertain their guests. Later in the novel, Ladislaw is also described as a dilettante artist by his German friend, a professional painter who works in a studio in Rome: "Oh, he does not mean it seriously with painting. His walk must be *belles-lettres*" (p. 215). When Dorothea tells Ladislaw about her difficulty to appreciate and enjoy painting, his learned and critical answer is conveyed through a modest and matter-of-fact manner:

[184] George Eliot, *Middlemarch*, introduction pp. viii, ix, xii, xiii.

> "Oh, there is a great deal in the feeling for art which must be acquired," said Will… "Art is an old language with a great many artificial affected styles, and sometimes the chief pleasure one gets out of knowing them is the mere sense of knowing. I enjoy the art of all sorts here immensely; but I suppose if I could pick my enjoyment to pieces I should find it made up of many different threads. There is something in daubing a little one's self, and having an idea of the process."
> "You mean perhaps to be a painter?" said Dorothea…
> "No, oh no," said Will, with some coldness. "I have quite made up my mind against it. It is too one-sided a life. I have been seeing a great deal of the German artists here: I travelled from Frankfort with one of them. Some are fine, even brilliant fellows—but I should not like to get into their way of looking at the world entirely from the studio point of view." (p. 206-207)

In this last utterance, Ladislaw seems to imply that professional art being too different from real life, or from the real world, he would not engage in this activity as a profession. Indeed, he finally embraces a political career at the end of the novel. However, with landscape painters such as Constable and Turner, then the Pre-Raphaelites, British painting also undertook important changes from the 1830s onward.

3.7 Social debates about science and culture in 19th-century education

The process of abstraction, inherent in the mathematization of physics throughout the 19th century, made the scientific representations of the world move away from common sense. From the 1850s, as further knowledge in physics needed a more structured training and teaching, it became the domains of specific departments of physics at university, while the role of science academies became limited to the symbolic recognition of the best scientists and to the production of reports and advice about the governance of science and technology. The time of learned "amateurs", such as Benjamin Franklin, Erasmus Darwin, Humphry Davy and Michael Faraday, who could make important discoveries though they had not followed a formal university curriculum during their youths, was over. That process of splitting science into disciplines was accompanied with the use of more sophisticated and expensive instruments, which generally became inaccessible to amateurs.[185]
The subject of science education, however, spread out of universities into the wider society, where it became a hot topic of debate among intellectuals and politicians during the second half of the 19th century.

In the 1840s, an economic recession occurred in Britain. Despite the increasing adoption of locomotives, steamboats and steamships, and hot blast iron smelting, British industrial supremacy was challenged by other European Countries, such as Belgium and France, which were beginning to develop their own industries. New technologies such as the electrical telegraph, widely introduced in the 1840s and 1850s in the United Kingdom and the United States, were not powerful enough to drive high rates of economic growth.[186] By the 1860s, it was becoming clear that any complacency about Britain's position in the world, or the state of its education system compared with that of

[185] Yves Gingras, *Histoire des Sciences*, pp. 100 and 120 (my translation).
[186] Source: Industrial Revolution - Wikipedia

continental countries, was misplaced: “the Paris Exhibition of 1867 revealed a high level of industrial technique in other countries, particularly Germany, and it had been made clear that this rested not only on a high standard of technical education but also on universal elementary schooling.”
Indeed, Victorian England had no state education: schools belonged mostly to the churches and had been allowed to develop in line with the country's class structure. Many groups had campaigned for more and better education, especially for the children of the working class, but they had not been supported by the middle and upper classes, who were 'fearful of state control of education' nor, at least before 1870, by the Liberal Party, which traditionally believed in freedom and diversity, and in 'the supreme virtue of limited government'. Sadly, when the British government finally began to acknowledge its responsibility for educating all its people, it not only allowed the class divisions to continue, but exacerbated them: three national education commissions were established, the reports of each—and the Acts which followed them between 1868 and 1870—relating to provision for a particular social class. Among these three Acts, the *1870 Elementary Education Act* made provision for the elementary education of all children aged 5-13, and established school boards to oversee and complete the network of schools and to bring them all under some form of supervision. Such a strategy, it said, would have to be affordable and acceptable to the many sectional religious interests. The Act required the provision of sufficient school places for all children, but it did not make education free (except in proven cases of poverty).[187]

In *Hard Times*, first published in 1854, Charles Dickens explored the social and economic challenges faced by the working class during the Industrial Revolution. From its very beginning, the novel suggests that 19th-century England’s overzealous adoption of industrialization threatens to turn human beings into machines by thwarting the development of their emotions and imaginations. In the imaginary city of Coketown, Mr Thomas Gradgrind, school owner and model of Utilitarian success, feeds his pupils and his family with facts, banning fancy and wonder from young minds:

> Thomas Gradgrind, sir. A man of realities. A man of facts and calculations. A man who proceeds upon the principle that two and two are four, and nothing over, and who is not to be talked into allowing for anything over… With a rule and a pair of scales, and the multiplication table always in his pocket, sir, ready to weigh and measure any parcel of human nature, and tell you exactly what it comes to. It is a mere question of figures, a case of simple arithmetic… In such terms…[he]…now presented Thomas Gradgrind to the little pitchers before him, who were to be filled so full of facts. Indeed… he seemed a kind of cannon loaded to the muzzle with facts, and prepared to blow them clean out of the regions of childhood at one discharge. He seemed a galvanizing apparatus, too, charged with a grim mechanical substitute for the tender young imaginations that were to be stormed away…
> ‘Bitzer,’ said Thomas Gradgrind. ‘Your definition of a horse.’
> ‘Quadruped. Graminivorous. Forty teeth, namely twenty-four grinders, four eye-teeth, and twelve incisive. Sheds coat in the spring; in marshy countries, sheds hoofs, too. Hoofs hard, but requiring to be shod with iron. Age known by marks in mouth’… (See an extract of Chapter II in Appendix 4).

The opposition of Gradgrind’s dry facts to the children’s emotions and imaginations in Dickens’s novel, though caricatural, seems not only to echo William Blake’s and John Keats’s reactions against the mathematical world of Newtonian physics (see pp. 37-38), but also to foresee the public debate

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[187] Derek Gillard, *Education in the UK: a history* (2018): Education in the UK: a history - Chapter 6 (education-uk.org)

about the teaching of the sciences and the humanities in students' education and their respective importance in the curriculum. Indeed, during the 1860s, there was much debate about the importance of science and technology in education, either as a result of concerns about Britain's declining economic position relative to other countries, or because science was recognized as an essential part of a complete education in its own right. Although the debate about science and technology attracted a great deal of attention both in the press and in parliament, with many distinguished figures making contributions, its effect in the schools was less than might have been expected. Indeed, in the 1860s and 70s there was an absence of any clearly defined core curriculum to meet the requirements of a rapidly changing world.[188]

Among those distinguished figures stood Matthew Arnold (1822-1888), an English poet and cultural critic who was also an inspector of schools for thirty-five years, and Thomas Henry Huxley (1825-1895), an English biologist and anthropologist who became known as "Darwin's Bulldog" for his advocacy of Charles Darwin's theory of evolution. Between these two men started a public controversy about the places of scientific instruction and classical humanism in Britain's education policies, underlaid by the larger philosophical issue about the grounds of knowledge and the relationship of knowledge to religion and ethics.

Caricature of Arnold by James Tissot published in *Vanity Fair*, in 1871 [189]

Caricature of Huxley by Carlo Pellegrini published in *Vanity Fair*, 1871 [190]

The importance of science in schools, colleges and universities was underlined in the eight reports of the *Royal Commission on Scientific Instruction and the Advancement of Science*, appointed in 1870. The Commission was chaired by William Cavendish (1808-1891), probably best known for

[188] *Ibid*

[189] Public Domain: Matthew Arnold Vanity Fair 11 November 1871 - Matthew Arnold - Wikipedia

[190] Public Domain: TH Huxley 41.5 KB - Thomas Henry Huxley - Wikipedia

founding the Cavendish Laboratory at Cambridge (see photo p. 69), where he also endowed the Cavendish Professorship of Physics, and included T. H. Huxley among its members.

In their sixth report, published in 1875, the Commissioners recommended that science should be taught for at least six hours a week and that it should form an important element in any leaving examination. In their last report, they argued that the government should include a Minister of Science or a Minister of Science and Education.

Five years later, the subject came under the spotlight again when A. J. Mundella, having achieved his long-standing aim of making elementary education compulsory, turned his attention to the provision of technical education. He secured the establishment of the Normal School of Science (despite the reluctance of the Treasury to fund the building), which opened in October 1881 with T. H. Huxley as Dean. However, government policy was to leave the provision of scientific and technical education to voluntary organisations and to exert indirect influence through syllabuses and examinations.[191]

From the earliest days of his career as Inspector of Schools, Matthew Arnold made his view clear that while not every student needed a classical education which included Greek and Latin, every student did need a balanced education which included both humanistic studies and scientific instruction. But by the end of the 1870s, faced with the success that science was having in establishing its new place in the modern curriculum, and to avoid the risk of a new imbalance in educational practices, Arnold became the champion of classical humanism.

In April 1879, in "A Speech at Eton," he attempted to reemphasize the moral dimensions of education which he thought modern science ignored. Thus, Huxley, the champion of science, replied to Arnold in his speech "Science and Culture" delivered in October 1880, saying that "the free employment of reason, in accordance with scientific method, is the sole method of reaching truth," and that such an "unhesitating acceptance of reason" was "the supreme arbiter of conduct." Their "amicable conflict" escalated through various speeches and lectures, but those they respectively delivered at the Royal Academy of Arts (RA) in April 1881 and May 1883 are of particular interest, because each man used arts as a third party to strengthen his argument against the other. Arnold, presenting literature as a "facultative extra, more or less interesting and ornamental" in their contemporary society, where science was presented as necessary, said, addressing the President of the RA:

> … you and I are in the same boat. Before their sister, Science, now so full of promise and pride, was born, there was Art and Literature, like twins together, innocently believing in their own necessity, as eager in the pursuit of the eternal and unseizable shadow, beauty, as if they were pursuing something positive.

The almost pathetic tone of his speech indicates how Arnold deeply felt the threat of modern science against the humanities. Two years later, Huxley, answering to Arnold's speech, said:

> … I am unable to understand how any one with a knowledge of mankind can imagine that the growth of science can threaten the development of art in any of its forms. If I understand the matter at all, science and art are the obverse and reverse of Nature's medal, the one expressing the eternal order of things in terms of feeling, the other in terms of thought.

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[191] Gillard D (2018), *Education in the UK: a history*, Chapter 6: www.education-uk.org/history

A month later, in the annual Rede Lecture at Cambridge that Huxley gave on the same day that Arnold received his honorary degree, June 13, 1883, though, he chose not to raise his voice in contention against Arnold, thus promulgating for both a separate peace. Maybe he thought that, once it becomes clear that irreconcilable differences exist in the first principles of the disputants, all debate should charitably cease. [192]

It is worth noting that the meaning of the term "humanities" in Arnold's speeches and 19th-century scholarship was much restricted than today's meaning. Stemming from the medieval *studia humanitatis* ("studies of humanity"), humanities encompassed then secular literary and scholarly activities (in grammar, rhetoric, poetry, history, moral philosophy, and ancient Greek and Latin studies). If, in the 18th century, they tended more to concentrate on Latin and Greek texts and language, ***by the 19th century***, when the purview of the humanities expanded, ***they begun to take their identity*** not so much from their separation from the realm of the divine as ***from their exclusion of the material and methods of the maturing physical sciences***, which tended to examine the world and its phenomena objectively, without reference to human meaning and purpose (*my emphasis*).[193]
To me, one of the origins of the gap between the sciences and the humanities which would be referred to as "the two cultures" by C. P. Snow in the 20th century, might come from the exclusive way (according to the Encyclopaedia Britannica's article) these "modern humanities" have defined their own identity since the last third of the 19th century: against science, or rejecting science from their "human" realm of knowledge, echoing Gradgrind's caricatural way of separating facts from emotion and imagination…

Moreover, arts were not included in the scope of humanities yet. Art education depended on institutions like the Royal Academy Schools (established in 1768), the Royal College of Art (1837) or the Royal Academy of Music (1822) in London, the Glasgow School of Art (1845) in Scotland, or on some individual initiatives: in 1868, for instance, the lawyer and philanthropist Felix Slade (1788–1868) bequeathed funds to establish three Chairs in Fine Art, to be based at Oxford University, Cambridge University and University College London, but with studentships only at London. In 1871, he funded a school where fine art would be studied within a liberal arts university and which would offer female students an education on equal terms as men from the outset.[194]
Traditionally, however, art students would simply apprentice themselves to someone who was already skilled in some sort of trade in exchange for food and housing. Many painters received training in this manner, copying or painting in the style of their teacher to learn the trade.
Thus, it is important to underline here that, even if Arnold and Huxley referred to the arts in their speeches to defend their different points of view regarding letters and science, in fact arts were not yet included in the school curriculum as part of a "balanced education." Fine arts were still regarded as "a facultative extra" for the educated upper and middle-classes, not a necessity for educating the masses (or working-classes). The place of arts in late Victorian society thus reflected the one that Eliot was giving to arts in the 1830s' fictitious society of Middlemarch (see above, p. 87).

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[192] David A. Roos, 'Matthew Arnold and Thomas Henry Huxley…' pp. 316-324
[193] Source: Classical scholarship | Definition, History, Scholars, & Facts | Britannica
[194] Source: History • Slade School of Fine Art (ucl.ac.uk)

Finally, it is not clear, in this debate about science and humanities, what places law and medicine, for instance, were supposed to occupy in Victorian society (regarded as "professions", they were taught in their own faculties at university). It would be even more tricky in 20th-century society to try to classify social sciences—like cultural (or social) anthropology, sociology, psychology, political science, and economics—according to this 19th-century binary division.

And yet C. P. Snow, "former chemist turned bureaucrat, novelist and pundit," relaunched the same kind of controversy with his 1959 Rede Lecture 'The Two Cultures,' [195] which was followed by "an attack, nearly three years later, by the literary critic Frank Leavis, the virulence of whose language still shocks to this day".[196] According to Frank A. James, such longevity suggests the existence of underlying issues, which have not gone away, including the anxiety of scientists about the place of science in culture and society and Britain's place in the world. "It was scarcely a coincidence that Snow's first outing of the idea was during the lead up to the Suez crisis, which demonstrably and unambiguously showed that British power had declined irreversibly". Both these underlying issues suggest a strong sense of insecurity and anxiety throughout large sections of British culture and society.

To me, these anxieties echo those that had brought about the Arnold-Huxley debate in a Victorian society which had lost its industrial supremacy.

[195] C.P. Snow, *The Two Cultures and the Scientific Revolution*, pp. 1-22

[196] Frank A. James, 'Introduction: Some Significance of the Two Culture Debate,' pp.108-109.

Conclusion

From the very beginning of this research paper (RP), I have underlined how complex and variable the meanings of the words art and science have been throughout history. Consequently, I chose a chronological and inclusive approach in studying the relationship of science and art (including literature) in Britain's "modern" history, highlighting the sustaining role of technology to further human knowledge throughout the so-called 'Scientific Revolution' and the 19th century.

Contrary to C.P. Snow's binary view of knowledge, split in two different cultures, I demonstrated throughout this RP that science and art are both ways of understanding our world. If natural science is a systematic approach to understand our physical world and its phenomena—establishing general facts and truths and connecting them together—the knowledge about our world acquired through the arts is no less authentic, but artists approach the world with another method, relying on emotion and expression, to reach truth. As Huxley underlined in one of his speeches (p. 90), science and art are "the obverse and reverse of Nature's medal", they are complementary and are both creative. Indeed, scientists need as much imagination as artists to think about the new things they need to discover and push the boundaries of knowledge.

Moreover, it is evident that disciplines like architecture and medicine cannot be classified in one of Snow's two cultures: to use a scientific metaphor, both science and art are parts of their DNAs.
If the Merriam-Webster defines architecture[197] in a nutshell as being "the *art* or *science* of building", according to the Encyclopaedia Britannica[198], architecture is "the *art* and *technique* of designing and building, as distinguished from the skills associated with construction" (my emphasis). However, in architecture, "techniques" depend heavily on mathematics, physics and applied sciences dealing with the resistance of materials and structures. From Greek and Roman monuments (p. 10) to Gothic cathedrals (p. 11), from the Iron Bridge (p. 58) and the Crystal Palace (p. 59) to the tallest skyscraper in Dubai, architecture has always evolved with the latest technical improvements and artistic styles. Similarly, whether medicine is defined as the *science* and *art*[199] or the *practice*[200] "dealing with the maintenance of health and the prevention, alleviation, or cure of disease," for Lydgate, the doctor in *Middlemarch*—and certainly for George Eliot, the novel's writer, too—the medical profession presents "the most perfect interchange between science and art" (p. 86), as we saw in this RP from Vesalius's *De Humani corporis fabrica* (pp. 18-19) to Bichat's and Pasteur's discoveries (pp. 82-83).

I also demonstrated that both science and art are combined in what we call today technology, engineering, or applied sciences, which help further human knowledge and achievements: from the first illustrated, printed book (pp. 17-19) to beautiful astronomy instruments (pp. 24-28, 32 and 39-42) and from the first metallic structures such as the iron bridge (p. 58) and the Crystal Palace (p. 59) to the photography (pp. 70-72). And these interrelations have continued during the following centuries. These last decades, not only have computers supported the development of sciences, but

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197 Architecture Definition & Meaning - Merriam-Webster
198 Architecture | Definition, Techniques, Types, Schools, Theory, & Facts | Britannica
199 Medicine Definition & Meaning - Merriam-Webster
200 Medicine | Definition, Fields, Research, & Facts | Britannica

they have also helped artists to create video games and stunning special effects in movies, thus blurring even more the borders between science and art and pushing further the boundaries of human imagination.

I also showed that for centuries, there was no gap between what we call today science and art in the prolific brains of polymath thinkers or inventors such as Aristotle (pp. 7-8), Vitruvius (pp. 10 and 17), Leonardo da Vinci (pp. 15-17), Galileo (pp. 27-30), Benjamin Franklin (p.24), Erasmus Darwin (46-47) and Humphry Davy (pp. 61-68). Of course, since the middle of the 19th century, the fields of knowledge have become too vast and specialized for a single human being to become an expert in many of them, but an inquiring mind can have very different interests in life and pursue them for its own pleasure. That is why it is so important that young people may be initiated to science, literature, and art at school from an early age, and this need has differently been considered in most educational systems of western countries from the last third of the 20th century. Indeed, as access to human knowledge and culture may be very different in families, depending on their social status and financial means, at least a balanced curriculum at school might offer an opportunity for children of less-privileged classes to open new doors to their imaginations. But this last subject, though captivating, lies far beyond my knowledge and the scope of this research paper.

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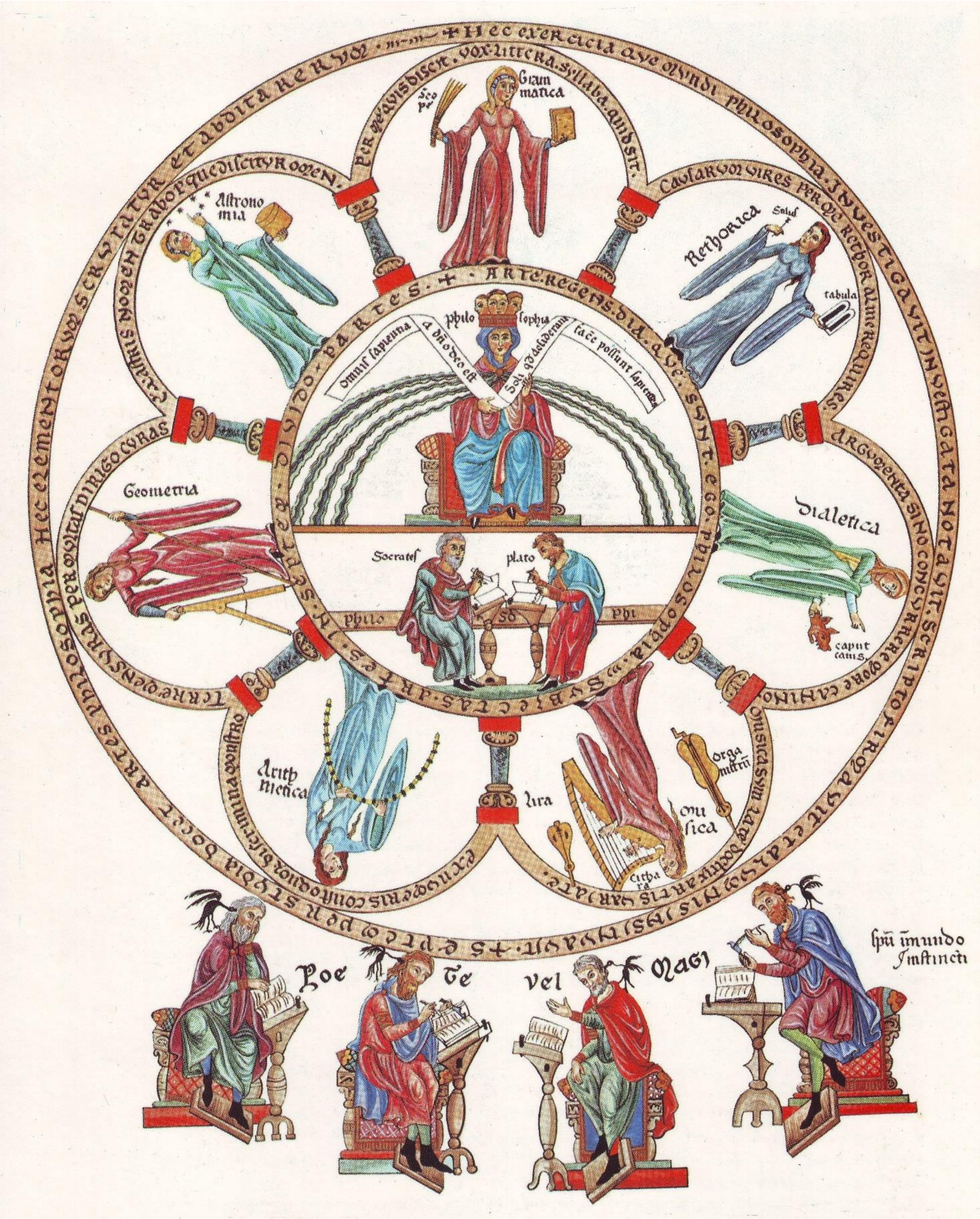
Appendix 1

The seven liberal arts in the ancient and medieval educational curriculum



Philosophia et septem artes liberales, "philosophy and the seven liberal arts."
From the *Hortus deliciarum* of Herrad of Landsberg (12th century) [201]

[201] Public Domain : [Hortus Deliciarum, Die Philosophie mit den sieben freien Künsten - Liberal arts education - Wikipedia]

Appendix 2

Three poems by Humphry Davy (1778-1829)

'The Massy Pillars of the Earth' (c. 1818)

The massy pillars of the earth,
The inert rocks, the solid stones,
Which give no power no motion birth,
Which are to Nature lifeless bones;
Change slowly; but this dust remains,
And every atom, measured, weigh'd,
Is whirl'd by blasts along the plains,
Or in the fertile furrow laid.
The drops that from the transient shower
Fall in the noon-day, bright and clear,
Or kindle beauty in the flower,
Or waken freshness in the air.
Nothing is lost. The etherial fire,
Which from the furthest star descends,
Through the immensity of space
Its course by worlds attracted bends,
To reach the earth; the eternal laws
Preserve one glorious wise design;
Order amidst confusion flows,
And all the system is divine.
If matter cannot be destroy'd,
The living mind can never die;
If e'en creative when alloy'd,
How sure its immortality!
Then think that intellectual light
Thou loved'st on earth is burning still,
Its lustre purer and more bright,
Obscured no more by mortal will.
The things most glorious on the earth,
Though transient & short-lived they seem,
Have yet a source of heavenly birth
Immortal, — not a fleeting dream.
The lovely changeful light of even,
The fading gleams of morning skies,
The evanescent tints of heaven,
From the eternal sun arise.

'And when the light of life is flying' (1825)

"And when the light of life is flying,
And darkness round us seems to close,
Nought do we truly know of dying,
Save sinking in a deep repose.
"And as in sweetest, soundest slumber,
The mind enjoys its happiest dreams,
And in the stillest night we number
Thousands of worlds in starlight beams;
"So may we hope the undying spirit,
In quitting its decaying form,
Breaks forth new glory to inherit,
As lightning from the gloomy storm."

Source: Lancaster University. *Humphry Davy: Laughing Gas, Literature, and the Lamp.* MOOC on Future Learn (Steps 2.3 and 2.4).

'The True Philosopher' (1825)

It is alone in solitude we feel
And know what powers belong to us.
By sympathy excited, and constrain'd
By tedious ceremony in the world,
Many who we are fit to lead we follow;
And fools, and confident men, and those who think
Themselves all knowing, from the littleness
Of their own talents and the sphere they move in,
Which is most little, — these do rule the world;
Even like the poet's dream of elder time,
The fabled Titans imaged to aspire
Unto the infinitely distant heaven,
Because they raised a pile of common stones,
And higher stood than those around them,
——— The great is ever
Obscure, indefinite; and knowledge still,
The highest, the most distant, most sublime,
Is like the stars composed of luminous points,
But without visible image, or known distance,
E'en with respect to human things and forms,
We estimate and know them but in solitude.
The eye of the worldly man is insect like,
Fit only for the near and single objects;
The true philosopher in distance sees them,
And scans their forms, their bearings, and relations.
To view a lovely landscape in its whole,
We do not fix upon one cave or rock,
Or woody hill, out of the mighty range
Of the wide scenery, — we rather mount
A lofty knoll to mark the varied whole. —
The waters blue, the mountains grey and dim,
The shaggy hills and the embattled cliffs,
With their mysterious glens, awakening
Imaginations wild, — interminable!

Source: Lancaster University. *Humphry Davy: Laughing Gas, Literature, and the Lamp.* MOOC on Future Learn (Step 2.5)

Appendix 3

Extracts from George Eliot's novel *Middlemarch*[202]

Criticisms of the medical profession in the 1830s:

> "...by confiding to you the superintendence of my new hospital, ... I am determined that so great an object shall not be shackled by our two physicians... And now I hope you will not shrink from incurring a certain amount of jealousy and dislike from your professional brethren by presenting yourself as a reformer."
>
> "I will not profess bravery," said Lydgate, smiling, "but I acknowledge a good deal of pleasure in fighting, and I should not care for my profession, if I did not believe that better methods were to be found and enforced there as well as everywhere else."
>
> "The standard of that profession is low in Middlemarch, my dear sir," said the banker. "I mean in knowledge and skill; not in social status, for our medical men are most of them connected with respectable townspeople here... I have consulted eminent men in the metropolis, and I am painfully aware of the backwardness under which medical treatment labours in our provincial districts."
>
> "Yes;—with our present medical rules and education, one must be satisfied now and then to meet with a fair practitioner. As to all the higher questions which determine the starting-point of a diagnosis—as to the philosophy of medical evidence—any glimmering of these can only come from a scientific culture of which country practitioners have usually no more notion than the man in the moon." (pp. 124-125)
>
> For it must be remembered that this was a dark period; and in spite of venerable colleges which used great efforts to secure purity of knowledge by making it scarce, and to exclude error by a rigid exclusiveness in relation to fees and appointments, it happened that very ignorant young gentlemen were promoted in town, and many more got a legal right to practise over large areas in the country. Also, the high standard held up to the public mind by the College of Physicians, which gave its peculiar sanction to the expensive and highly rarefied medical instruction obtained by graduates of Oxford and Cambridge, did not hinder quackery from having an excellent time of it; for since professional practice chiefly consisted in giving a great many drugs, the public inferred that it might be better off with more drugs still, if they could only be got cheaply, and hence swallowed large cubic measures of physic prescribed by unscrupulous ignorance which had taken no degrees. Considering that statistics had not yet embraced a calculation as to the number of ignorant or canting doctors which absolutely must exist in the teeth of all changes, it seemed to Lydgate that a change in the units was the most direct mode of changing the numbers. He meant to be a unit who would make a certain amount of difference towards that spreading change which would one day tell appreciably upon the averages, and in the mean time have the pleasure of making an advantageous difference to the viscera of his own patients. But he did not simply aim at a more genuine kind of practice than was common. He was ambitious of a wider effect: he was fired with the possibility that he might work out the proof of an anatomical conception and make a link in the chain of discovery. (pp. 145-146)

[202] See the edition in Works Cited

Lydgate's vocation:

> [H]is scientific interest soon took the form of a professional enthusiasm: he had a youthful belief in his bread-winning work, not to be stifled by that initiation in makeshift called his 'prentice days; and he carried to his studies in London, Edinburgh, and Paris, the conviction that the medical profession as it might be was the finest in the world; presenting the most perfect interchange between science and art; offering the most direct alliance between intellectual conquest and the social good…
> There was another attraction in his profession: it wanted reform… He went to study in Paris with the determination that when he came home again he would settle in some provincial town as a general practitioner, and resist the irrational severance between medical and surgical knowledge in the interest of his own scientific pursuits, as well as of the general advance: he would keep away from the range of London intrigues, jealousies, and social truckling, and win celebrity, however slowly, as Jenner had done, by the independent value of his work… (p. 145)
> Lydgate was ambitious above all to contribute towards enlarging the scientific, rational basis of his profession. The more he became interested in special questions of disease, such as the nature of fever or fevers, the more keenly he felt the need for that fundamental knowledge of structure which just at the beginning of the century had been illuminated by the brief and glorious career of Bichat… This great seer did not go beyond the consideration of the tissues as ultimate facts in the living organism, marking the limit of anatomical analysis; but it was open to another mind to say, have not these structures some common basis from which they have all started … What was the primitive tissue? In that way Lydgate put the question… And he counted… for taking up the threads of investigation—on many hints to be won from diligent application, not only of the scalpel, but of the microscope, which research had begun to use again with new enthusiasm of reliance. Such was Lydgate's plan of his future: to do good small work for Middlemarch, and great work for the world. (pp. 147-149)

Casaubon's research for the *Key to All Mythologies*

> Dorothea by this time… had understood from him the scope of his great work, also of attractively labyrinthine extent… he told her how he had undertaken to show (what indeed had been attempted before, but not with that thoroughness, justice of comparison, and effectiveness of arrangement at which Mr. Casaubon aimed) that all the mythical systems or erratic mythical fragments in the world were corruptions of a tradition originally revealed. Having once mastered the true position and taken a firm footing there, the vast field of mythical constructions became intelligible, nay, luminous with the reflected light of correspondences. But to gather in this great harvest of truth was no light or speedy work. His notes already made a formidable range of volumes, but the crowning task would be to condense these voluminous still-accumulating results and bring them, like the earlier vintage of Hippocratic books, to fit a little shelf…
> Dorothea was altogether captivated by the wide embrace of this conception. Here was something beyond the shallows of ladies' school literature: here was a living Bossuet, whose work would reconcile complete knowledge with devoted piety; here was a modern Augustine who united the glories of doctor and saint (pp. 24-25)

…is revealed obsolete before being finished:

> "…Such power of persevering devoted labour as Mr Casaubon's is not common'…

> "No, indeed," he answered, promptly. "And therefore it is a pity that it should be thrown away, as so much English scholarship is, for want of knowing what is being done by the rest of the world. If Mr. Casaubon read German he would save himself a great deal of trouble."
> "I do not understand you," said Dorothea, startled and anxious.
> "I merely mean," said Will, in an offhand way, "that the Germans have taken the lead in historical inquiries, and they laugh at results which are got by groping about in woods with a pocket-compass while they have made good roads."... Poor Dorothea felt a pang at the thought that the labour of her husband's life might be void... (pp. 207-208)
> "...Why should Mr. Casaubon's [books] not be valuable, like theirs?" said Dorothea, with more remonstrant energy...
> "That depends on the line of study taken," said Will... "The subject Mr. Casaubon has chosen is as changing as chemistry: new discoveries are constantly making new points of view. Who wants a system on the basis of the four elements, or a book to refute Paracelsus? Do you not see that it is no use now to be crawling a little way after men of the last century—men like Bryant—and correcting their mistakes? (pp. 221-22)

Ladislaw's painting according to Mr Brooke:

> "You are an artist, I see," said Mr. Brooke, taking up the sketchbook...
> "No, I only sketch a little. There is nothing fit to be seen there," said young Ladislaw...
> "Oh, come, this is a nice bit, now. I did a little in this way myself at one time, you know. Look here, now; this is what I call a nice thing, done with what we used to call *brio*." Mr. Brooke held out towards the two girls a large coloured sketch of stony ground and trees, with a pool...
> Mr. Brooke said, smiling nonchalantly...
> "But you had a bad style of teaching, you know—else this is just the thing for girls—sketching, fine art and so on. But you took to drawing plans; you don't understand *morbidezza*, and that kind of thing. You will come to my house, I hope, and I will show you what I did in this way," he continued, turning to young Ladislaw...
> "We will turn over my Italian engravings together," continued that good-natured man. "I have no end of those things, that I have laid by for years. One gets rusty in this part of the country, you know... You clever young men must guard against indolence. I was too indolent, you know: else I might have been anywhere at one time." (pp. 79-80)

Appendix 4

Extract from *Hard Times*, Chapter 2, by Charles Dickens

Thomas Gradgrind, sir. A man of realities. A man of facts and calculations. A man who proceeds upon the principle that two and two are four, and nothing over, and who is not to be talked into allowing for anything over… With a rule and a pair of scales, and the multiplication table always in his pocket, sir, ready to weigh and measure any parcel of human nature, and tell you exactly what it comes to. It is a mere question of figures, a case of simple arithmetic… In such terms Mr. Gradgrind… no doubt, substituting the words 'boys and girls,' for 'sir'… now presented Thomas Gradgrind to the little pitchers before him, who were to be filled so full of facts. Indeed… he seemed a kind of cannon loaded to the muzzle with facts, and prepared to blow them clean out of the regions of childhood at one discharge. He seemed a galvanizing apparatus, too, charged with a grim mechanical substitute for the tender young imaginations that were to be stormed away…

'Bitzer,' said Thomas Gradgrind. 'Your definition of a horse.'

'Quadruped. Graminivorous. Forty teeth, namely twenty-four grinders, four eye-teeth, and twelve incisive. Sheds coat in the spring; in marshy countries, sheds hoofs, too. Hoofs hard, but requiring to be shod with iron. Age known by marks in mouth.'…

'Girl number twenty,' said the gentleman…'So you would carpet your room… with representations of flowers, would you?' said the gentleman. 'Why would you?'

'If you please, sir, I am very fond of flowers,' returned the girl.

'And is that why you would put tables and chairs upon them, and have people walking over them with heavy boots?'

'It wouldn't hurt them, sir. They wouldn't crush and wither, if you please, sir. They would be the pictures of what was very pretty and pleasant, and I would fancy—'

'Ay, ay, ay! But you mustn't fancy,' cried the gentleman, quite elated by coming so happily to his point. 'That's it! You are never to fancy.'

(Then Mr. M'Choakumchild, the new teacher, is asked to begin his first lesson)

So, Mr. M'Choakumchild began in his best manner. He and some one hundred and forty other schoolmasters, had been lately turned at the same time, in the same factory, on the same principles, like so many pianoforte legs. He had been put through an immense variety of paces, and had answered volumes of head-breaking questions. Orthography, etymology, syntax, and prosody, biography, astronomy, geography, and general cosmography, the sciences of compound proportion, algebra, land-surveying and levelling, vocal music, and drawing from models, were all at the ends of his ten chilled fingers. He had …taken the bloom off the higher branches of mathematics and physical science, French, German, Latin, and Greek. He knew all about …. all the histories of all the peoples, and all the names of all the rivers and mountains, and all the productions, manners, and customs of all the countries, and all their boundaries and bearings on the two and thirty points of the compass... If he had only learnt a little less, how infinitely better he might have taught much more! (…)

Say, good M'Choakumchild. When from thy boiling store, thou shalt fill each jar brim full by-and-by, dost thou think that thou wilt always kill outright the robber Fancy lurking within—or sometimes only maim him and distort him!

Source: Hard Times | Project Gutenberg