Science and Technology in the Middle Ages

In the 17th century many learned people looked back on the centuries preceding their own time, and they believed they were seeing “darkness.” The “Dark Ages,” that is what they called the millennium from the 6th to the 16th century A. D. They were convinced that the light of Greek and Roman Antiquity had been eclipsed by the hordes of Barbarians who had destroyed the ancient civilization. They thought it had taken roughly 1,000 years for humanity to start out anew, switching on the light of humanism, reason, and truth again which they said had characterized the Classical World. Both the classical civilizations of Antiquity and the “new” age, which had started with the Renaissance and the Age of Humanism, were deemed to have been “enlightened” periods; the Dark Ages, they said, had been caught up in superstition and ignorance.

What the “enlightened” scholars were so proud of was a view of the world and everything that was in it, which had taken shape from the 16th century onwards. It seemed to diametrically contradict the scientific view of the Middle Ages. They asserted that all of these views must have been wrong because medieval scientific thinkers had been preoccupied by religion, and their thinking had mainly served purposes of the Catholic Church. Moreover, they assumed that scholars of the Middle Ages had stubbornly adhered to ideas, assumptions, and convictions which went back to “authorities” like the Bible, the books of the Church Fathers, or, later, the texts by Greek and Roman philosophers and scientists. They claimed, for example, that when medieval scholars made statements about central scientific problems like the order of the universe, they would refer to the doctrines of those authorities. In this way, scientific argument was made up of deductions based on the assumptions of these authorities. In almost no case, they alleged, had they been seriously doubted, or even allowed to be doubted.

However, these “enlightened” critics ignored the fact that the Middle Ages had relied upon the very classical texts of the Antiquity which they cherished so much. They also ignored the fact that it had been during the Middle Ages that the outlines of modern science had emerged. They would not admit that their own generation was standing on the shoulders of medieval intellectuals.

The emergence of scientific thinking and methodology

During the first centuries of the Middle Ages, scholars concentrated their intellectual activities mainly on the Christian faith. The medieval intellectual élite was recruited from the clergy, so it was no wonder that these men were not inclined to investigate scientific matters. If, however, some practical purpose made it necessary for clerics to make use of mathematics or physical knowledge, things were different. For example, it was important for the Church to determine the date for Easter, which would not have been possible without some knowledge of the motions of the Moon and the Sun or some basic mathematics. Monastic life, which depended upon the painstaking observation of times for prayer, would have been impossible without careful observation of the movement of the stars. Medical and botanical knowledge was used for the Church’s duty to help and tend the sick.

Scientific issues were hardly ever discussed in depth by the intellectual élite, however. One of the reasons, according to the modern historian Michael Postan, was that medieval intellectuals simply “had no time for occupations like science.” Another reason certainly was that most clerics and scholars of the early Middle Ages did not have access to the vast amount of scientific literature written in Greek before and during the Roman Empire. The language of natural philosophy during all of Antiquity had

been Greek, and, for most scholars, Greek was a language that was lost. Latin prevailed in Western Christianity, but only very few books written in or translated into Latin contained scientific subject matter.

One of the few Greek philosophers whose works had been translated into Latin was Plato. For most of the thinkers of the early Middle Ages, Plato's works provided suitable clues for the view of the natural world in the light of Christianity. It was Plato's conviction that the natural world was just a sub-category of the world of "ideas," in which everything concrete was contained in form of impeccable models. "Ideas" were the perfect framework for the rather imperfect forms to be found in the concrete world. Substituting "God" for the concept of "idea," early medieval thinkers regarded the natural world as the concrete representation of the Creator's intention made imperfect by the Fall. The world, they claimed, would be improved upon by God's will if he thought it necessary. An inherent order of the natural world, they argued, was out of the question.

From the High Middle Ages on, however, Latin Christianity made contact with Muslim scholars, mainly in Spain. These made them acquainted with Aristotle and other Greek philosophers, since Muslim thinkers had eagerly adopted Greek knowledge and translated much of Greek scientific literature into Arabic. Much of this literature had also been further studied and annotated by Arab and Jewish scholars. Now, after the "discovery" of this treasure trove of knowledge, Western scholars translated these books into Latin and made them accessible to western intellectuals. It was via Aristotle and other Greek philosophers' ideas that the study of nature appeared on the horizons of Christian scholars. In his book "Physics," Aristotle (384–322 BC) teaches to think of the creation of the world as being based on nature only. Metaphysical considerations, like God's creation of the world within six days, were therefore not accepted as relevant. From this point on, medieval thinkers became doubtful whether the spheres of religion and philosophy were related.

Geniuses like *Peter Abelard*, *Albertus Magnus* or *Thomas Aquinas* produced important results on their way to make Christian doctrine compatible with Greek philosophy. These efforts were mainly carried on by the school of intellectuals called "Scholasticism". A large number of Scholastics taught at universities, the new type of schools of higher learning, which were meant to concentrate the intellectual élite of Europe to serve the needs of the Church and the monarchs of the emerging European nation states. The scholastic philosopher *William of Ockham* (1288–1347/48) eventually arrived at the solution that "faith" (i. e. theology) and "reason" (i. e. philosophy) should be regarded as independent of each other. Before him, *Albertus Magnus* (about 1200–1280), another of the eminent scholastic philosophers, had pointed out that, when investigating nature, scholars should not try to understand how God the Creator used his creation to work wonders. Rather, they should try to understand what happens in nature in natural ways as being a result of natural causes.

Important scientific progress and considerable technological advances were in fact made during the Middle Ages, from about the 12th century on. One eminent medieval intellectual, Roger Bacon, may serve as an example.

Roger Bacon (1214–1294) was an English Franciscan monk who enjoyed the friendship and support of Pope Clement IV. It was this pope who inspired him to sum up his learning in a series of books, the most important of which bears the title *Opus Maius* (1266–1268). Here, Bacon expounds on scientific and mathematical matters. Bacon was convinced that no true knowledge could be arrived at

without an empirical basis. He detested prejudice which was expressed by authority, by uncritical reliance upon authorities, by the force of habit, and by the lack of self-criticism. He only accepted knowledge which was acquired from the original source. To his mind, *scientia experimentalis* – science based upon empirical methods, i. e. the cycle of *observation*, *hypothesis*, *experimentation*, and the possibility of objective *verification* – was the only "true" science and theoretical speculation or assumption would only lead away from truth. Bacon also promoted mathematics which he regarded as the ABC of philosophy. Unfortunately for him (and the ensuing ages), Bacon was accused of heresy after the death of Pope Clement IV., and his ideas had little resonance at his time.

The World-view of the Middle Ages

The view of heaven and earth during the Middle Ages was based upon concepts developed by Aristotle (384–322 BC) and by the Greek geographer and mathematician Ptolemy (AD 100–170). Christian considerations were later added onto this construct of ideas to make up the Christian world-view that was to prevail until the 17th century.

MEDIEVAL MODIFICATION OF PTOLEMAIC COSMOLOGY: In the Middle Ages, the earth was considered to be the stationary centre of the universe, with the Sun, the Moon, and the planets turning around it in spheres of their own. These were meant to be hierarchically arranged and were assumed to consist of crystalline material to which the celestial objects were fixed. The "heavens" were thought to be suspended above and around the universe. These heavens were considered to be the realms of the angels and – the outermost one – of God. This geocentric universe was in perfect harmony with the Christian doctrine of God the Creator of Heaven and Earth; both the universe and the earth were believed to be finite. People were convinced that God had created the earth for his own purpose and glory; one day, if the Lord pleased, he would put an end to it.

HEAVEN AND EARTH IN ARISTOTELIAN NATURAL PHILOSOPHY: Large parts of Aristotle's natural philosophy perfectly matched the Christian world-view and were regarded as axiomatic. Aristotle had divided the universe into an earthly realm and a higher celestial one. These two realms were thought to be different regarding their physical nature, the laws they obeyed, and their ultimate purpose. The four elements to be found on earth (earth, water, fire and air) were absent from the celestial realm, which was composed of divine ether. This was so pure, fine, clear, and spiritual that the earth did not contain even the slightest traces of it. Therefore celestial objects moved in perfectly circular orbits around the earth. Heavy elements were, by their sheer weight, bound to the earth, while the lighter elements had the natural tendency to fly up into the sky.

The Complexity of Scientific and Technological Innovation during the Middle Ages

People of the Middle Ages had to face a great number of questions and pressing problems. More and more, they were willing to answer or solve them with the help of methods and knowledge defined and acquired in their own times. Some of the inventions and discoveries made in the Middle Ages (e. g. the invention of gunpowder) led to problems which asked for immediate reaction in a variety of fields. Innovation came from political leaders, for example, men of the Church, merchants, navigators, soldiers, artists, and architects. In order to find solutions, more and more intellectuals dared to study nature objectively and to apply the results of contemporary scientific thinking. This led to an enormous increase

in the quantity and quality of innovation and eventually resulted in the "Scientific Revolution" of the 16th and 17th centuries. The key sciences were mathematics, chemistry, and astronomy.

ALCHEMY: One important stimulus was the monarchs' growing demand of coinable precious metals; mining made giant strides to meet this demand. New pumping devices, new machines for lifting heavy loads, and new methods of finding and extracting of metals were developed. Metallurgy and metal-working were carried to new heights during the 16th century. Alchemists, who were eager to solve the problem of the shortage of gold in their laboratories, more or less accidentally laid the foundation of modern Chemistry.

FIREARMS, ARCHITECTURE, FORTIFICATION: The invention of gunpowder and firearms made mathematical knowledge indispensable; artillery without ballistic competence would have been inefficient. The knowledge of geometry and statics enabled architects of the Middle Ages to construct such wonder-works like Gothic cathedrals. Also, the sophisticated fortifications constructed in Italy, France, and England during the 15th and 16th centuries would not have been effective if their architects had not applied mathematical principles.

VISUAL ARTS: Progress in visual arts was made via the study of light and pigments, and the new principles of perspective and proportion required careful study of the mathematical principles upon which they are founded.

ANATOMY: It was also painters and sculptors who, in the 15th and 16th centuries, made intensive studies of the human body. They improved their knowledge of human anatomy by drawing upon discoveries made by anatomists who, in contempt of a Church law, had started to dissect human cadavers and to study in detail the structure of the human body.

EXPLORATION OF THE EARTH: From the 14th century onwards, western merchants travelled as far as China (e. g. Marco Polo, q.v.) and brought back information on the hitherto unknown countries in the East. Based upon new and more precise maps, the world was explored by Portuguese and Spanish sea captains (Bartholomeu Dias, Vasco da Gama, Columbus, q.v.), and the view of the Earth became shattered. The culmination point of this process was reached when Nicolaus Copernicus disproved the geocentric conception of the universe.

BOOK PRINTING: The 15th century saw one of the greatest inventions in the history of humankind. In 1450 Johannes Gutenberg, a citizen of the German town of Mainz, was able to *print* books. Himself a gifted craftsman and engineer possessing a thorough knowledge of metallurgy, he developed the prototype of the printing press, which made it possible for humanity to spread and give access to the knowledge of the world to everybody everywhere on the globe, and to accumulate and store it in libraries, the ever-growing treasure houses of human knowledge.

THE CALENDAR: The Church almost never interfered with technological or scientific progress. On the contrary, there was a strong motive for the clergy to solve some of the problems posed by the Bible which mathematics, astronomy, and science were able to provide solutions to: the problem of the exact date for Easter which led to the publication of a reformed Christian calendar and chronology. The reform of the Christian calendar was the result of a commission of astronomers, presided over by the popes, which reacted to information provided as early as the 14th century. Pope Gregory XIII in 1582 concluded this effort by his bull *Inter Gravissimas*, thus introducing the Gregorian Calendar which, in the centuries to follow, came to be accepted as the established civil calendar worldwide.

Leonardo da Vinci

The end of the 15th century saw one of the greatest geniuses in the history of mankind. The following biographical sketch shows that Leonardo da Vinci (1452–1519) was a man whose knowledge comprised the totality of medieval science.

Leonardo da Vinci was born roughly 250 years after Roger Bacon, in 1452, and died in 1519. He was an artistic genius, but he also mastered the scientific, mathematical, and technological knowledge of his time. Leonardo's intellectual curiosity was boundless. He was conversant in aerodynamics, human anatomy, biology, physiology, hydro-dynamics, mechanics, ballistics, mineralogy, geology, and many more scientific subjects. The results of his research were carefully written down in a large number of notebooks which contain notes on why he conducted specific studies, which method he pursued, which observations he made and conclusions he arrived at. Most of the topics were carefully illustrated. Some of them foreshadowed scientific theories and technological developments of the 19th and 20th centuries. Since, however, he never wrote them out in a coherent form and his notes were written in a cryptic language, (and in mirror script), his findings were disseminated only a long time after his death. It is remarkable that all of his designs, inventions, and theories were based upon careful and systematic observation. So much is certain: had they been published in his lifetime, scientific progress would have accelerated considerably.

Leonardo drew upon his scientific knowledge for the invention of a large number of ingenious machines and devices. Among his inventions were flying machines, parachutes, an underwater diving suit, the hydrometer, hydraulic pumps, crank mechanisms, musical instruments, artillery and hundreds more. They were never put into practice, though, as Leonardo's ideas had little resonance in his times. It was the generation after him that realised his innovative fantasy and scientific genius. During his lifetime, he was very much in demand as an engineer; the cities of Florence and Venice employed him as a builder and advisor on technological matters. In his latter years, he worked for the king of France. He achieved considerable renown as a civil engineer even in Turkey, where Sultan Beyazid II asked him to design a bridge spanning the Golden Horn. Leonardo designed a single span bridge 220 meters wide which the sultan thought was impossible to realise.

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