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The role of the mechanical clock in medieval science

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The invention and spread of the mechanical clock is a complex and multifaceted historical phenomenon. Some of these facets, such as its social impact, have been widely studied, but their scientific dimensions have often been dismissed. The mechanical clock was probably born as a scientific instrument for driving a model of the universe, and not only natural philosophers but also kings, nobles and other members of the social elites showed an interest in clocks as scientific instruments. Public clocks later spread a new way of telling time based on equal hours, laying the foundations for changes in time consciousness that would accelerate scientific thinking.

What is a mechanical clock? The answer to this question depends on whom you ask. Today, most people consider it a time-telling instrument. Actually, it is a pillar of Western society; we unconsciously use it numerous times every day, but we usually do not reflect on the fact that if all clocks were to simultaneously fail, Western society would collapse. Many historians, influenced by contemporary culture, have explained the origin of the mechanical clock through the assumed birth of a new necessity of time consciousness in 13th and 14th century Europe. Werner Sombart and Lewis Mumford, for example, found this new necessity's origin in strictly organized monastic life. Mumford asserted that the monastery was the natural context for the invention of the mechanical clock.[1] Other historians have considered the advent of the clock to be a secular phenomenon that was linked to a change in urban time consciousness. Jacques Le Goff developed the oft- referred to notion of a struggle between 'church time', the old religious time told by the bells, and 'merchant's time', a new secular time measured by the newly invented mechanical clock, which the rising merchant class demanded.[2] Social history perspectives such as these have been widely accepted and frequently used by historians.

Many of these ideas originate from misconceptions about what the mechanical clock was in the 14th and 15th centuries. Its birth and diffusion is a very complex phenomenon involving many factors; telling time is just one and perhaps not even the most relevant factor. A complete explanation of this phenomenon would exceed this paper's aim, so we will focus on the mechanical clock's scientific links before the invention of the pendulum in the context of the so-called Scientific Revolution.

From the point of view of the history of technology, a mechanical clock is a device with at least three elements. First, a clock requires a driving force to run the clockwork. Hanging weights have been used for this purpose from the earliest history of the clock; but beginning in the first third of the 15th century, the spring was also used to drive small domestic clocks.[3] The second required element is an indicator showing the time information generated by the clock. Bells and dials have been the most common clock indicators from the outset. The third essential feature is the escapement, a mechanical device that stops the fall of the weight at intervals and makes the clock run regularly. The escapement transforms the rotary motion of the wheels into an oscillating motion. Weight driven devices and time indicators existed from late antiquity, but the escapement only appeared in the last third of the 13th century and is the key technological novelty that allowed for the construction of the first mechanical clock. The escapement is the key element that distinguishes the mechanical clock from other devices such as the clepsydra, another time telling instrument in which water is both the driving force and the escapement.

Limitations on the measurement of time in the natural sciences

From a history of science perspective, when the clock is considered a time device, it is linked with two elements: the 'modern time concept' and 'modern time reckoning'. The latter could be defined in opposition to 'old time reckoning', characterized by the separation of day and night with two series of unequal hours for each. Various systems of modern time reckoning have been used across the centuries, but all of them use equal or equinoctial hours that a mechanical clock can easily measure. The oldest known modern system is Italian reckoning, which counted twenty-four hours from one sunset to the next. (Fig. 1) Another

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[1] G. Dohrn-Van Rossum, *History of the hour. Clocks and modern temporal orders*, Chicago, The University of Chicago Press, 1996, p. 10.

[2] J. Le Goff, *Time, work and culture in the Middle Ages*, Chicago, University of Chicago Press, 1980, p. 51–52.

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[3] E. Morpurgo, *Ĺorigine dellórologio tascabile*, Roma, Edizioni La Clessidra, 1954, p. 24.

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Fig. 1. 'Italian clock' in the Rialto Place, Venice, Italy. The reckoning of the twenty-four hour day begins at the sunset.
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Fig. 2. Richard of Wallingford, abbot and scientific instrument maker, 14th century. British Library, MS Cotton Claudius E. IV, f. 201r. © The British Library Board, UK.

method is the half clock, which counted two twelve-hour series that began at midday and at midnight, no matter the length of day and night. Midday was the most common reference for adjusting clocks in Western Europe.[4]

The modern time concept can be defined as abstract, mathematical and independent from nature; time is a magnitude that can be measured with the appropriate instrument. In the Middle Ages, the modern time concept took a prototypical form that was more theoretical than practical; it existed only in science and was told with astronomical instruments, such as astrolabes or quadrants. In 1484, Bernhard Walther was probably the first known person to use a clock to measure modern time accurately for scientific purposes. He used the clock during an observation of a Mercury transit across the sun, but he was forced to count the teeth of the hour wheel to know the time in minutes. Three years after this event, he used the clock again during an eclipse.[5] Despite its mechanical limitations, his clock was acceptably accurate, though he used it only twice, as far as we know.

Walther's effective use of the clock was exceptional for his day. 15th century clocks were generally bad timekeepers, and they could not show minutes on their faces because of their inaccuracy. From the second half of the 16th century, there was a search for a reliably accurate clock, for astronomy and for finding longitude at sea, that promoted progress in horological technology. Subsequently, the cross-beat escapement, spiral spring, pendulum and marine chronometer appeared, all great technical inventions that changed mechanical clock history. Before these inventions, especially the pendulum, the mechanical clock was generally not suitable for scientific time measurement. The case of Bernhard Walther is the exception that confirms the rule.

These limitations did not mean that the mechanical clock was scientifically useless during this period or that it had no connection with science. Some historians have hypothesized that astronomy encouraged the invention of the mechanical clock.[6] An important support for this hypothesis is a commentary on the *Sphere* of Sacrobosco by Robertus Anglicus published in 1941 by Lynn Thorndike.[7] In this well-known text, Anglicus expressed his desire to have a self-moving mechanical machine to drive a model of the universe, and he stated that scientific instrument makers were searching for a way to make such a machine. The commentary dates back to 1271, and it is been assumed that the mechanical clock was invented after this date; however, no certain information or concrete facts now substantiate that claim. Non-scientific motives, such the construction of monastic alarms, could have also encouraged the invention of the mechanical clock.[8] We actually do not know exactly where, when and why the mechanical clock was invented, but the hypothesis that it was invented to satisfy the scientific requirements of an exclusive scholarly group is feasible.[9]

Some of the earliest clockmakers were also natural philosophers or passed through a university. Richard of

[4] G. Dohrn-Van Rossum, *History of the hour. Clocks and modern temporal orders*, Chicago, The University of Chicago Press, 1996, p. 113–117.

[5] D.B. Beaver, 'Bernard Walther: Innovator in astronomical observation', in *Journal for the History of Astronomy*, 1 (1970), p. 40–41.

[6] Derek J. De Solla Price, *On the Origin of Clockwork, perpetual motion devices and compass*, Washington, Smithsonian Institution, United States National Museum, 1959, p. 86.

[7] L. Thorndike, 'Invention of the mechanical clock about Ad 1271', in *Speculum*, 16 (1941), p. 242–243.

[8] L. Mumford, *Technics and civilization*, New York, Harcourt, Brace and Company, 1934, p. 13.

[9] J.D. North, *God's Clockmaker. Richard of Wallingford and the invention of time*, London-New York, Hambledon and London, 2005, p. 160–166.

Fig. 3. Astronomical clock of Padova, Italy. Originally built in the 14th century by Jacopo Dondi, Giovanni's father.
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Wallingford (c. 1292–1336), Giovanni Dondi (c. 1330–1388) and Jean Fusoris (c. 1365–1436) are still well-known medieval clockmakers who designed outstanding astronomical clocks. The son of a blacksmith, Wallingford studied at Oxford when he was a monk at Saint Albans Abbey (Fig. 2). He inherited his father's metal working ability and acquired the astronomical knowledge to design the St. Albans clock at Oxford.[10] The son of a doctor and clockmaker, Giovanni Dondi taught at the University of Padua and designed a legendary astronomical clock that showed the motions of the sun, the moon and the planets. The clockwork was extremely complicated with elliptical and irregular gears. This outstanding and legendary machine was probably destroyed at the end of the 15th century, but it has never been forgotten.[11] Jean Fusoris was a physician, mathematician, astronomer and scientific instrument maker. He built the monumental clock for the Bourges cathedral with astronomical indicators and a spherical clock driven by its own weight. He also worked for the Duke of Burgundy and the Duke of Orleans among others[12] (Fig. 3).

All these clockmakers are well-known historical figures in the history of science who constructed or designed clocks for showing a scientific subject: the universe. Their works are not conclusive evidence of the mechanical clock's invention as a scientific instrument, but they show it had a connection with medieval science.

Astronomical use of clocks out of the academic sphere

Domestic mechanical clocks appeared in European royal courts in the mid-14th century at the latest. In the 15th century, clocks became commonplace and were present in the houses of aristocrats and other wealthy people. In general they were appreciated for being exclusive items and sometimes also for having astronomical indicators. Kings and nobles showed an interest in astronomy before the invention of the mechanical clock. A well-known example is Alphonse X 'The Wise', the 13th century Castilian king who promoted the *Libros del saber de astronomia*, an encyclopedic treatise on astronomy and astrology, which described some instruments, including clepsydrae, sundials and other types of non mechanical clocks[13] (Fig. 4). In the 14th century Peter IV of Aragon was very interested in astronomy and he had astrolabes, quadrants, mechanical clocks and other instruments in his royal palaces. He paid various Jewish clockmakers for repairing and keeping his clocks in good working condition.[14] Peter IV, in 1376, gave an outstanding astronomical clock to his daughter Leonor, who was married to the crown prince of Castile. He sent her a letter to describe it and explain how it worked. It had three bells, a moon indicator and a twenty-four hour astrolabe face with three tympanums that covered the latitudes between 38° and 44°, the range in which all territories of the kingdom of Aragon were located. The king told his daughter that she must select the correct tympanum depending on the latitude where the clock was used. The king also pointed out to his daughter that it would show her the day and night hours, the zodiac sign of the sun, the ascendant and other astronomical data for astronomical or astrological purposes.[15]

The king's letter shows that this item was not a simple clock for telling time, but a complex instrument whose user should have basic astronomical knowledge to understand its visual indicators. Peter IV's letter to Leonor drew attention to the astronomical indicators of the clock, suggesting he conceived of it as a scientific instrument rather than a mere ornament. Leonor's marriage to the Castilian crown prince was intended as the seal of a peace treaty signed by Aragon and Castile, and the two were married the year before she received the clock. Because of this political context, the clock can also be interpreted as a diplomatic gift.[16] In summary, this document shows that astronomy and astrology were of interest not only to academics and researchers and that the objects associated

[10] J.D. North, *God's Clockmaker. Richard of Wallingford and the invention of time*, London-New York, Hambledon and London, 2005, p. 8 and 23.

[11] G. Brusa, *L'arte dell'orologeria in Europa. Sette secoli di orologi meccanici*, Busto Arsizio, Bramante Editrice, 1978, p. 26.

[12] G. Brusa, *L'arte dell'orologeria in Europa. Sette secoli di orologi meccanici*, Busto Arsizio, Bramante Editrice, 1978, p. 33.

[13] A.J. Cardenas, *A study and edition of the Royal Scriptorium manuscript of 'El Libro del Saber de Astrologia' by Alfonso X, el Sabio*, Ann Arbor, *Mi.* University of Wisconsin, 1974.

[14] C.F.C. Beeson, *Perpignan 1356. The making of a Clock and Bell for the King's Castle*, London, The Antiquarian Horological Society, 1982, p. 2.

[15] For an English translation of the description, see C.F.C. Beeson, 'Perpignan 1356 and the earliest clocks', *Antiquarian Horology*, vol. 6 (June 1970), p. 408. See also C.F.C. Beeson, *Perpignan 1356. The making of a Clock and Bell for the King's Castle*, London, The Antiquarian Horological Society, 1982, p. 6.

[16] A study on the political significance of this clock: V. Perez Alvarez: 'Mechanical clocks in the medieval Castilian royal court', in *Antiquarian Horology*, vol. 34–4 (December 2013), p. 489–502.

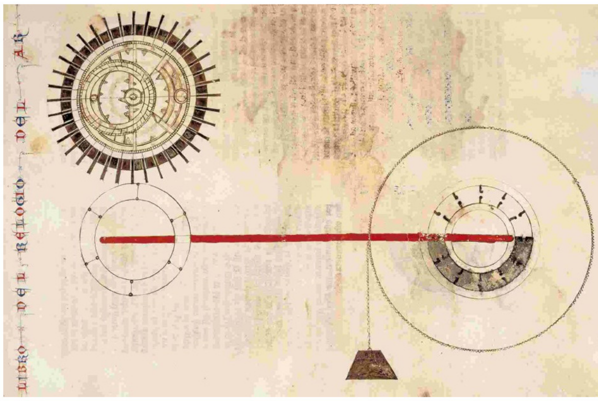

Fig. 4. A mercury clepsydra with an astrolabe dial, from the *Book on the Knowledge of astrology*, by Alphonse X 'The Wise', 13th century.
Universidad Complutense de Madrid, BH, MSS, 156, f. 194v. © Universidad Complutense de Madrid, Spain.

with them served also as prestige objects for social distinction.

Mechanical clocks and clock hours were occasionally used to register significant astronomical events such eclipses. As long as these events were believed to influence human life, astronomers and many others were interested in them. These events can be found in chronicles, annals and many different archival sources.

The chapter acts of Leon Cathedral have two interesting registers of astrological events. Leon is a historical city in northwestern Spain. Its gothic cathedral preserves excellent archival collections, including the chapter act series that begin in the early 15th century. We can find many daily time references in these acts, mostly canonical hours, middays, sunrises and sunsets, but there are also two clock-time references in this period, both recording eclipses. The first one describes the lunar eclipse of 17 February 1421:

> *Este dia, a las seys horas despues de mediodia, començo a oscurecer la luna, e duro el eclipssy fasta las siete horas e media e mas tienpo en tanto que duro el eclipssy dos horas de rrellox*[17]

This excerpt can be translated as follows:

> *This day, six hours after midday, the moon began to darken, and the eclipse continued until half past seven or later, so the eclipse lasted two clock hours*.

The second one is the total solar eclipse of 29 July 1478, described as follows:

> *Ovo eclinsi en el sol entre las doze oras e la una despues de medio día, e oscureciose el sol e parecieron las estrellas en el cielo, e duro por poco espacio*.

This excerpt can be translated as follows:

> *A solar eclipse took place between twelve hours and one hour after midday, and the sun darkened, the stars appeared on the heavens, and it lasted very few moments*.

The former act mentions the word clock to define the hour type used for measuring the eclipse's length. The time was not accurately measured in a modern sense, but we can verify the data with Calsky.[18] This online application uses UTC, and Leon is located at about 5°31′ W; we have subtracted 22 min from the times given by Calsky to obtain the local time. For the 1421 event, the moon rose at 17:39 partially eclipsed; the totality was between 18:36 and 20:07; and the partial eclipse ended at 21:09 Both events occurred and the calculations of Calsky agree with the data from the chapter acts, so the times were well registered.

The Castilian term *relox*, and its different forms, derive from the Latin term *horologium*, a word which preceded the invention of the mechanical clock. In the 14th and 15th centuries an *horologium* or a *relox* could mean a calendar, an astrolabe, a quadrant, a clepsydra, a mechanical clock, just a bell, or any other instrument for time telling. So, when this term is found in a medieval document, it does not always refer to a mechanical clock. The mechanical clock spread modern time reckoning across Europe, and pushed the construction of scales of clock hours on old instruments like astrolabs or quadrants. So, a clock time reference does not necessarily imply that a mechanical clock was used, but only that modern time reckoning has been introduced. In the chapter acts of Leon Cathedral the length of the lunar eclipse is expressed in *horas de relox*, that is in 'clock hours.' This is synonymous with 'equinoctial hours', and in contrast to canonical hours, which were more frequently used in Leon's chapter acts. Here there is no reference to a particular mechanical clock, but to the type of hours shown by mechanical clocks. The times of the beginning and the ending of both events are not explicitly defined as 'clock hours' because, as the reckoning begins at midday, it is obvious they are equinoctial clock hours.

Now the question is whether a mechanical clock or any other instrument was used to find the times of these eclipses, particularly the earliest one (Fig. 5). The oldest evidence of a mechanical clock's existence in the Cathedral of Leon dates back to 1424, three years after the lunar eclipse. This evidence appears in another chapter act about a pension payment to the clock keeper because he had retired after working in the cathedral for many years.[19] This mention almost certainly proves that a mechanical clock was running during the 1421 lunar eclipse. Because of the ambiguity of the term *relox* at this time, we cannot confirm that the cathedral's mechanical clock was used to record the eclipse's duration, but it likely was. Regardless, the fact that equal hours and modern time reckoning are used only twice in the 15th century Leon cathedral chapter acts and both instances record meaningful astronomical events shows a connection between the mechanical clock and astronomy, a scientific discipline.

[17] Archive of Leońs Cathedral, Chapter Acts, N. 9798. 1421, February, 17.

[18] http://www.calsky.com/ September 23, 2013.

[19] Archive of Leońs Cathedral, Chapter Acts, N. 9800, 1424, August, 4.

Fig. 5. The clock tower of the Leon Cathedral, Spain, 15th century.
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Similar uses of clock time can be found in other chronicles or annals, for example, in the *Anales de Garci Sanchez*, written in Seville after 1469, the final record-year of this registry.[20] The author worked for Seville's city council, and his presence is recorded there in November 1443.[21] The *Anales* explored a wide range of issues, mostly relating to Seville, but some episodes occured in Cuenca and different Castilian locales (for those relating to the king). Some facts were accurately dated with the full date and the time in clock hours—and sometimes in canonical hours. One chronicled event occured in 1432, and the others dated from 1453 to 1469 during the author's lifetime. There are no earlier events registered with clock hours, probably because they were not often used previously. Garci Sanchez only gave accurate dates with hours for meteorological, astrological and political events. Three astrological events were lunar eclipses, but only the first eclipse record included its start and end in clock hours:

> *Sabado en la noche, 3 dias de septiembre, a hora de las ocho, año de 1457, hizo grande eclipse la luna, y se torno fasta la mitad muy negra, y de la otra mitad como ha de estar. Y a las diez horas de la noche torno a esclarecerse, y a las doce horas de la dicha noche esclareció toda; y ansy estuvo eclipsada quatro horas.*[22]

[20] J.M. Carriazo: 'Anales de Garci Sánchez, jurado de Sevilla', in *Anales de la Universidad Hispalense*, 14 (1953), p. 3–63.

[21] J.M. Carrizao: 'El Apéndice, referido a Cuenca, de los «Anales de Garci Sánchez, jurado de Sevilla»', in *En la España Medieval*, 1 (1980), p. 60.

[22] J.M. Carriazo: 'Anales de Garci Sánchez, jurado de Sevilla', in *Anales de la Universidad Hispalense*, 14 (1953), p. 176.

This excerpt can be translated as follows:

> *Saturday night, the 3rd day of September, at the eighth hour, the year 1457, there was a great lunar eclipse, and one half of the moon became very dark and the other half as she has been. And at the tenth hour of the night she began to be illuminated and at the twelfth hour of the night she became completely illuminated; she was thus eclipsed for four hours.*

According to Calsky, the eclipse occurred between 20:00 and 23:30, and the totality occurred between 21:04 and 22:15 in local time. Once again, these Calsky data confirm that the eclipse occurred and was correctly measured within the reliability range for that time. Only the description of the eclipse type seems incorrect here; according to Calsky, it was a total eclipse, but Garci Sanchez suggests it was partial. Just the hour length is noted in the other two lunar eclipse records. In these *Anales*, clock time is used to date other facts, for example, to register a crown prince's birth:

> *Miercoles a la una hora despues de la medianoche, 15 dias de noviembre deste año de 1453, nascio el infante don Alfonso...*

This excerpt can be translated as follows:

> *Wednesday at one hour after midnight, 15 days into November of this year of 1453, the prince don Alfonso was born...*

It was very common to make note of the birth hour of future kings, at least in the 15th century. The interest in accurately knowing the birth moment can be potentially explained by the desire to generate his horoscope, but this record also possibly suggests the widespread use of the mechanical clock and modern time consciousness. Garci Sanchez makes note of his coronation ceremony fourteen years later at one o'clock at night, his birth hour, probably to emphasize the ceremony's legality.

Conclusions

From its earliest moments, the mechanical clock has been a prestige object. It was a self-moving machine that captured people's attention in the 14th and 15th centuries. Clocks were very unusual and so expensive that only wealthy institutions and affluent people could afford them. As a time-telling instrument, they played increasingly important roles in the organization of urban daily life and in activity coordination. At the same time that it was becoming a common urban accessory, the clock was gradually used to institute time regulations. The clock determined the opening and closing of markets and city doors, the summons to city council, deadlines for auctions, and so on.

Europe's introduction of the mechanical clock is a complex issue, and the historiography has explored these roles in a way that often undervalues or even denies its relationship to science. From our perspective, systematically and accurately measuring every quantifiable parameter to their smallest possible units or finest degrees is an exemplar of scientific practice. Thus, when we know that medieval mechanical clocks were so inaccurate that they could not show minutes, we are in danger of assuming clocks could not have served a scientific function prior to the 17th century. In medieval thought reason played a more important role than the observation of nature; medieval science was in general more qualitative than quantitative and more symbolic than current scientific thought, so the mechanical clock had more significance as a symbol than as a time measurer. Scientific thinking did not exist in the Middle Ages as it does today, but medieval men also wished to increase their knowledge of the natural world and the created universe. They used different methods to acquire this knowledge and generated valid conclusions that laid the foundations for modern science.

The strong scholarly commitment to science was obvious, but other people approached science in different ways, sometimes voluntarily to satisfy personal interests or perhaps for social purposes. Others did not have these interests, but they lived in cities and towns with public clocks. Originally, these new self-moving machines may have amused urbanites, but people probably did not pay attention to the continuous time indication until clock-time regulations were established for daily activities. When ordinary people were compelled to use clocks, a long transition process toward a more abstract concept of time began. This shift is the primary achievement of the mechanical clock and its main conceptual novelty, as its role as a model of the universe had been played by clepsydrae in previous centuries. The mechanical clock was likely born to meet scientific needs, but when it was put in the service of a wide range of people, it then promoted and popularized scientific thinking.