

Science and public knowledge

Renaissance to Enlightenment

Lecture 4 · ENG 151

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What makes a demonstration convincing?

An audience watches an experiment.
People respond with curiosity, distress and distraction.

What can they observe? What must they trust the demonstrator to explain?



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Joseph Wright, An Experiment on a Bird in the Air Pump, 1768

Evidence, authority and participation

A convincing demonstration needs an observable result and a defensible explanation.

A witness should be able to ask how the apparatus works, what might go wrong and whether the result can be repeated.

The scene also raises an ethical question: does learning justify every way of producing evidence?

15th–18th centuries: our route

The fifteenth and sixteenth centuries: books, workshops and the reconsideration of inherited knowledge.

The seventeenth century: instruments, experiments and mathematical explanations.

The eighteenth century: academies, encyclopedias and debate about who may use and challenge knowledge.

15th century: learning and upheaval

Greek texts and scholars reached Italy through contacts that began before Constantinople fell in 1453.

Italian cities supported art, craft and humanist scholarship. Elsewhere in Europe, readers and workshops developed related activities.

Political and religious upheaval shaped opportunities for learning. It did not produce one uniform European experience.



Images associated with Italian Renaissance culture

Northern Renaissance

Artists, printers and readers adapted Renaissance interests north of the Alps.

The Reformation made religious authority and access to texts matters of intense public dispute.

Natural inquiry developed within these societies, alongside religious commitment, patronage and conflict.



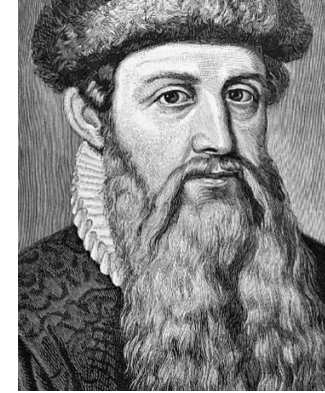
A northern European scene of village life

15th century: the printing workshop

Gutenberg's work in Mainz combined movable metal type with a system for producing books in repeated copies.

Type, ink, paper, skilled labour and investment all mattered. The press was part of a working process.

Printing had earlier histories in East Asia. Gutenberg marks a major European development, not the beginning of all printing.



Gutenberg portrait and a historical printing workshop

What repeated copies changed

Readers in different places could consult closely matching pages and diagrams.

A correction or criticism could circulate alongside the work it challenged. Printing also reproduced mistakes and polemics.

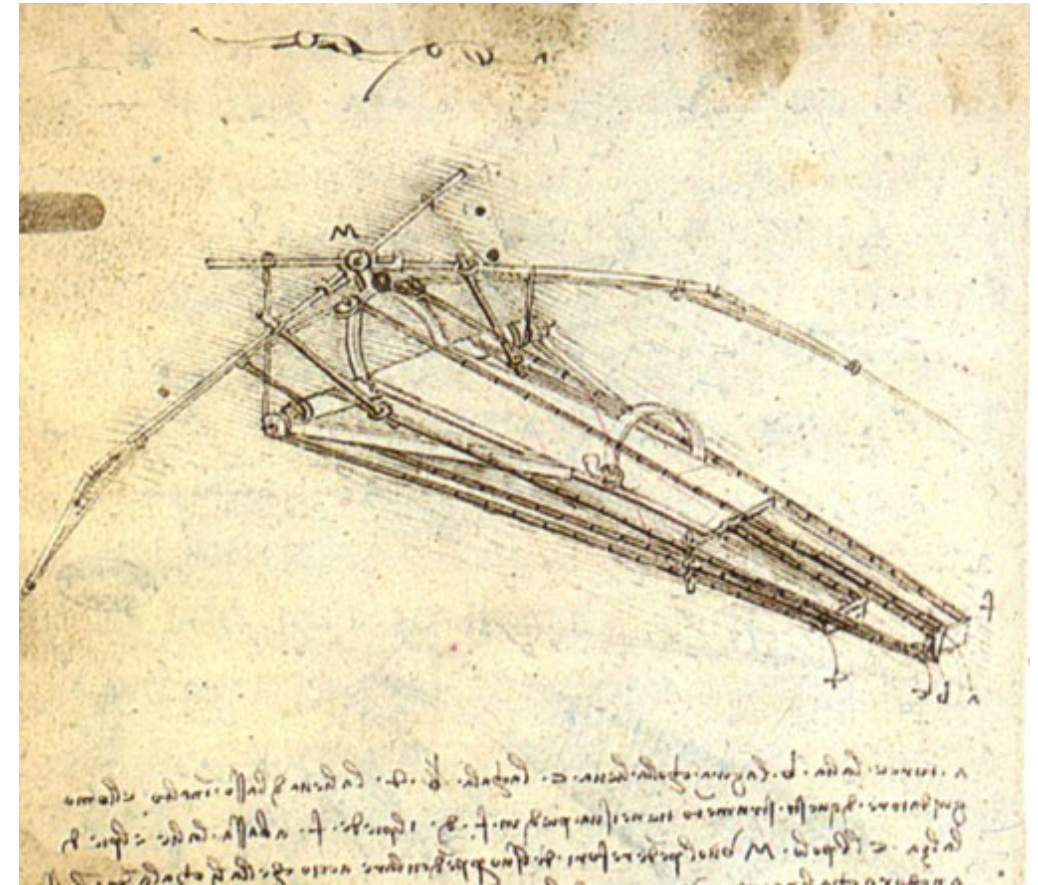
Access still depended on literacy, language, cost and permission to publish. More copies did not mean equal participation.

16th century: knowledge in workshops

Artist-engineers recorded mechanisms in notebooks and illustrated books.

Drawing helped communicate arrangements that were difficult to describe in words.

A proposed machine and a successfully built machine are different achievements. Construction also required materials, skill and testing.



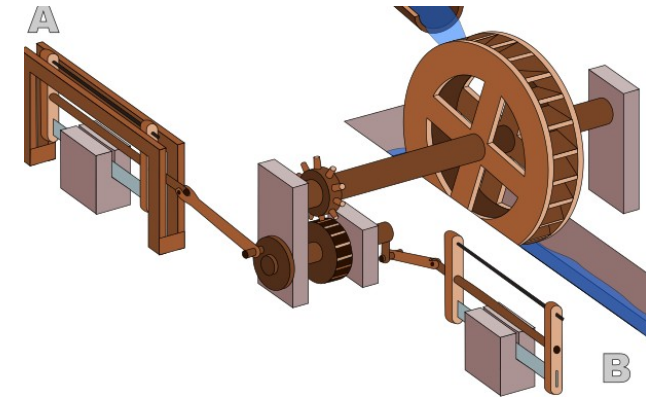
Mechanical design in a Renaissance notebook

Cranks and connecting rods

A rotating crank can drive a rod back and forth. The same relationship can transmit motion in the other direction.

Such mechanisms predate the Renaissance. Engineers extended their applications in pumps and other machinery.

The useful idea is the conversion of motion, not a single invention suddenly creating mechanization.



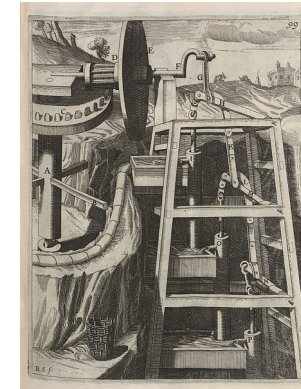
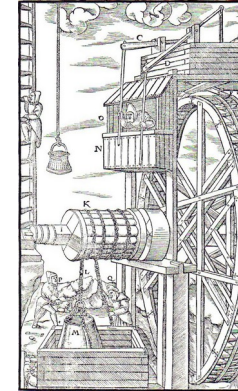
Modern reconstruction and historical drawing of mechanisms

16th–17th centuries: water and work

Water power could drive equipment for lifting ore or moving water.

The mechanical arrangement had to fit the available power, load and site.

These examples connect practical engineering with the later factory story. Their existence does not yet imply industrial production.



Mine hoist, 1556, and pump illustration, 1661

Navigation and the reach of knowledge

European ocean voyages extended trade and imperial power, drawing on shipbuilding, instruments and navigational knowledge.

Maps accumulated reports from many people. Some information served conquest and control as well as travel.

Longitude remained difficult to determine at sea. A useful chart could reduce uncertainty without eliminating it.

1543: two books, two investigations

Copernicus published *De revolutionibus*, presenting a moving Earth and a Sun-centred arrangement.

Vesalius published *De humani corporis fabrica*, joining anatomical description with detailed images.

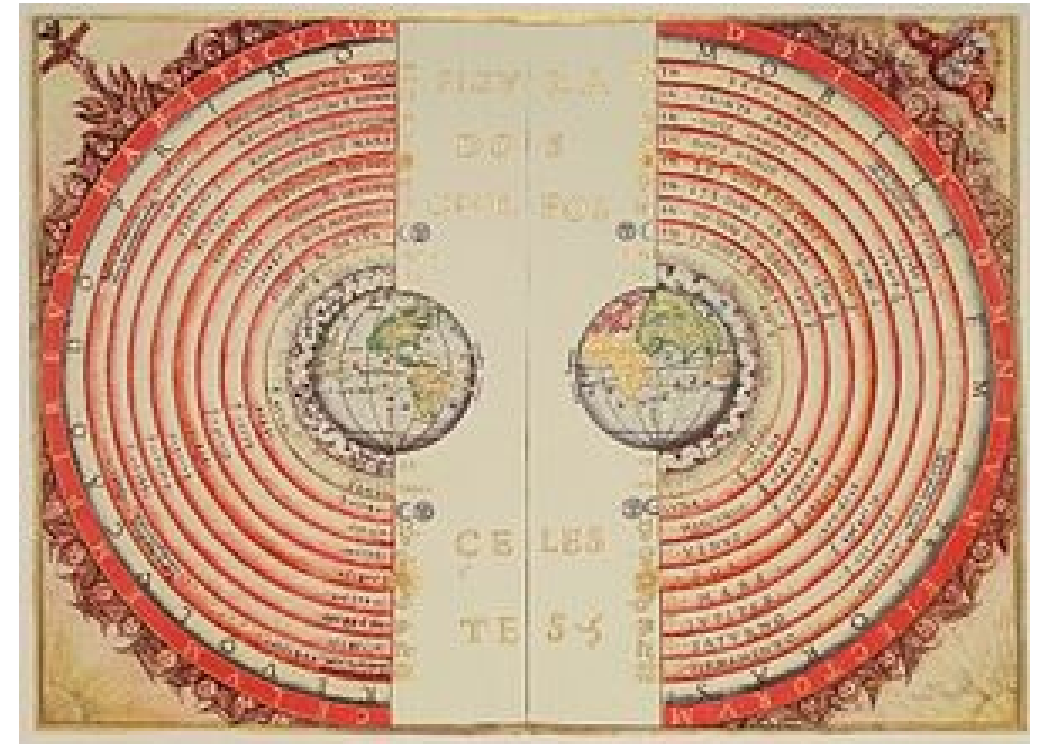
1543 is a useful historical landmark. Changes in astronomy and medicine still depended on work before and after these books.

16th century: inherited astronomy

Ptolemaic astronomy placed Earth at rest and used combinations of circular motions to describe planetary appearances.

A model was judged partly by how well it organized observations and enabled predictions.

Reconsidering it required more than declaring an old authority mistaken: a competing account had to do useful explanatory work.



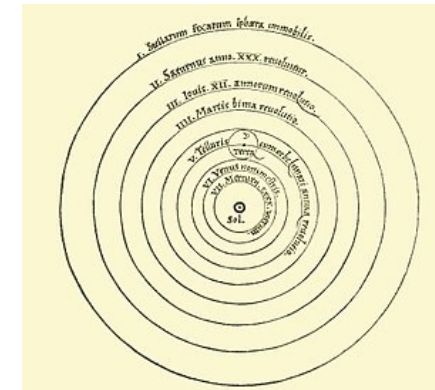
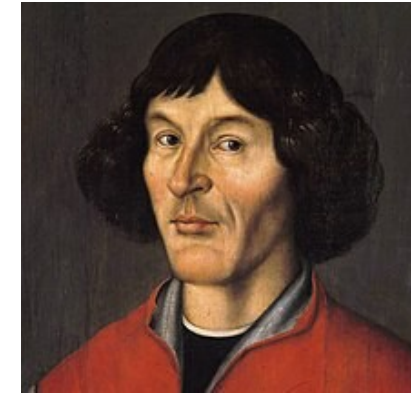
Historical representation of an Earth-centred cosmos

Copernicus: a moving Earth

Copernicus placed Earth among the planets and gave it daily rotation and an annual orbit.

Apparent retrograde motion could be understood through the relative motions of Earth and another planet.

His model still used circles and additional geometrical devices. It was not the complete modern account.



Copernicus and the planetary arrangement in De revolutionibus

A different view of apparent motion

Imagine overtaking a slower vehicle. For a short time it appears to move backwards relative to you.

Earth overtaking an outer planet offers an analogous way to understand apparent retrograde motion.

This is an explanatory analogy, not a scale model of an orbit. A complete account must also match measured positions.

17th century: Tycho and Kepler

Tycho Brahe assembled exceptionally careful observations before the astronomical telescope became available.

Kepler used observations, especially of Mars, to develop planetary laws involving elliptical orbits and changing speed.

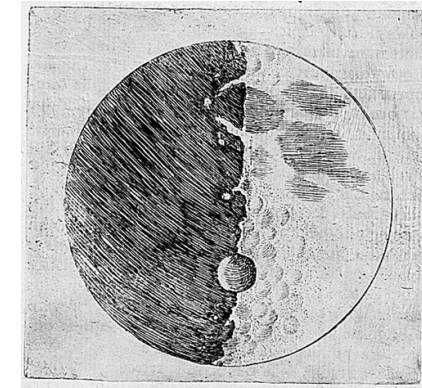
Mathematical success required allowing the evidence to challenge the assumed shape of the orbit.

1609–1610: Galileo's telescope

Galileo improved and used a telescope to study objects that appeared very different through the instrument.

The Moon's uneven surface and the satellites of Jupiter challenged familiar assumptions about the heavens.

Instrument-based claims also raised questions of trust: could observers distinguish a real feature from an optical effect?



Galileo portrait and a telescopic drawing of the Moon

What the phases of Venus showed

Galileo observed a fuller range of phases than the traditional Ptolemaic arrangement allowed.

The observations supported Venus moving around the Sun.

They did not by themselves prove that Earth moves. Tycho's alternative also allowed Venus to orbit the Sun while Earth remained at rest.

Observation and conclusion

Observation: small bodies repeatedly change position near Jupiter in a regular pattern.

Supported conclusion: not every celestial body revolves directly around Earth.

Further claim: Earth itself moves. That requires additional argument and evidence. One striking observation rarely settles every part of a theory.

1633: Galileo and authority

Galileo's defence of a moving Earth became entangled with scriptural interpretation and institutional authority.

In 1633 the Roman Inquisition convicted him, and he spent his remaining years under house arrest.

The conflict matters, but neither “all religion opposed science” nor “evidence settled everything immediately” explains the history.



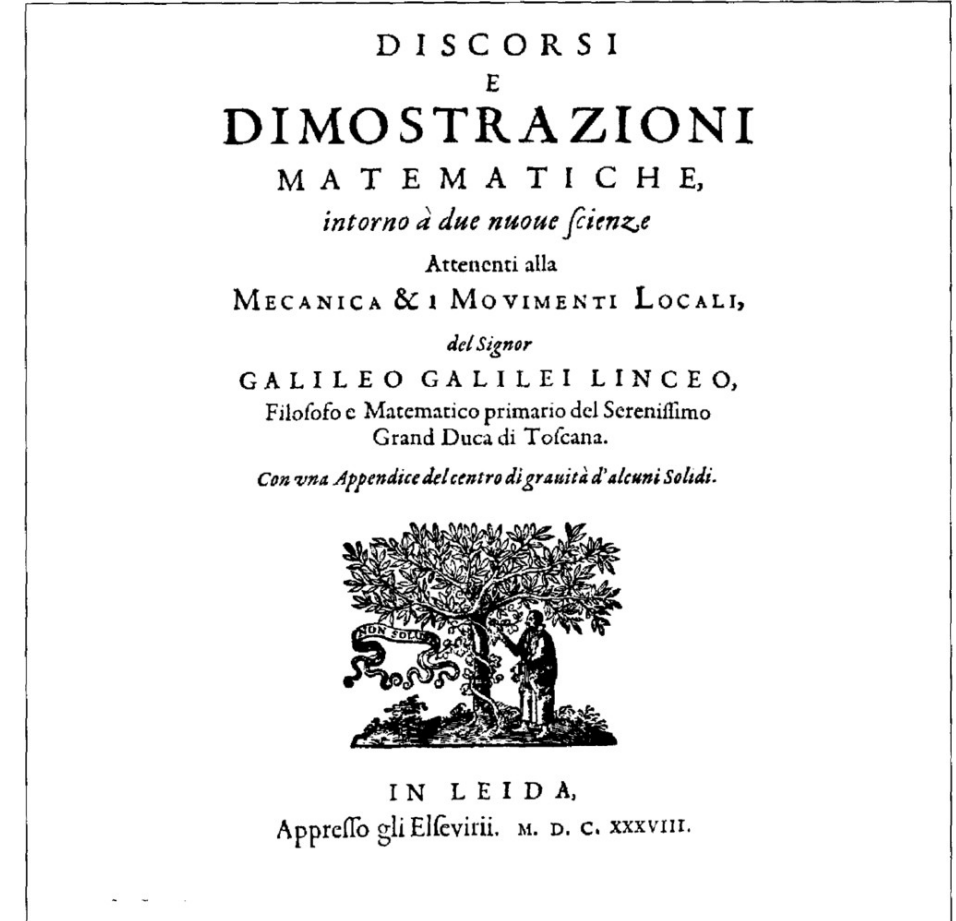
Cristiano Banti, Galileo Facing the Roman Inquisition, 1857

1638: Two New Sciences

Galileo's later book examined motion and the strength of materials through mathematical reasoning and physical problems.

Its diagrams connect geometrical arguments with the behaviour of bodies.

The book appeared in Leiden in 1638. Scientific work could circulate through publishing networks despite restrictions on its author.



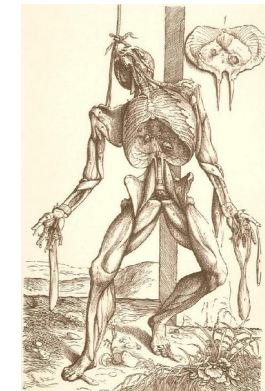
Title page of Galileo's Two New Sciences, 1638

1543: Vesalius and the body

Vesalius made direct examination of human anatomy central to his account of the body.

Careful description and images exposed discrepancies between human bodies and inherited anatomical claims.

This built on earlier dissection and teaching. A new book could challenge authority while still using parts of an older tradition.



Vesalius and an anatomical illustration

1628: Harvey and circulation

Harvey brought observations of the heart and veins together with arguments about the quantity of blood moved.

Repeated pumping would imply an implausibly large supply if blood were continually made and consumed instead of circulating.

The vein illustrations make a procedure inspectable. A strong explanation brings several kinds of evidence into agreement.

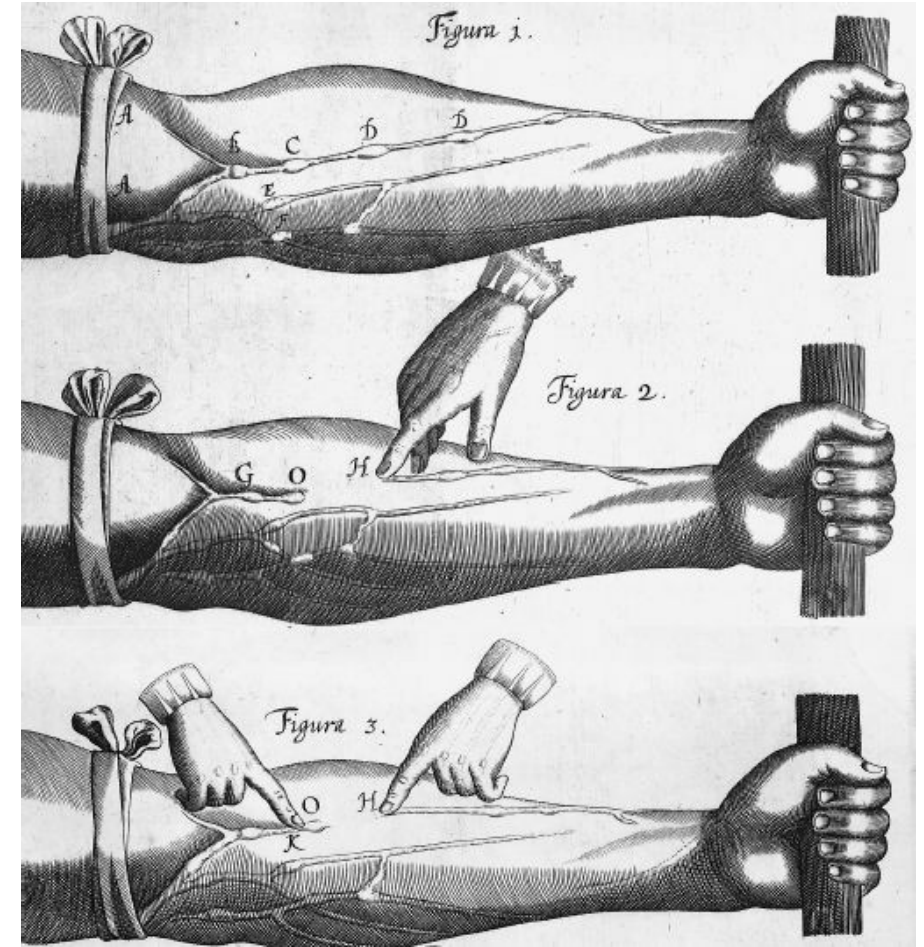


Illustration of investigations of veins associated with Harvey

A quantitative argument

Illustrative assumptions: 50 millilitres per beat and 60 beats per minute imply 3 litres passing through the heart each minute.

That would amount to 180 litres per hour if every beat required newly made blood.

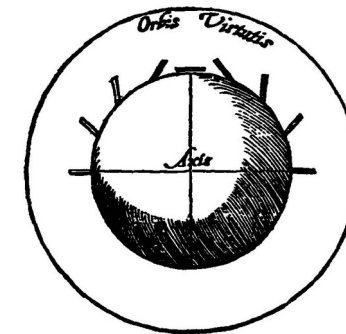
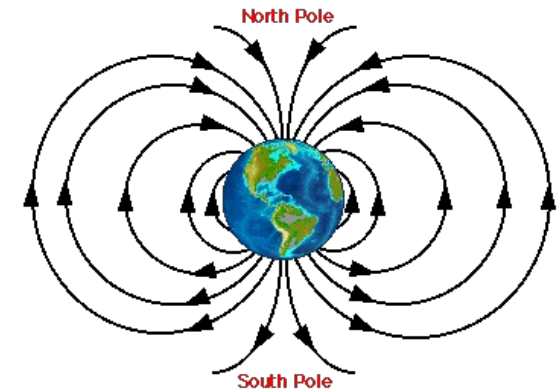
This is modern teaching arithmetic, not Harvey's reported measurement. Its purpose is to show how estimating quantity can test an explanation.

1600: Gilbert and magnetism

William Gilbert's *De Magnete* treated magnetic behaviour as a subject for systematic investigation.

A magnetized sphere provided a model for thinking about Earth and the compass.

A model can reproduce selected behaviour without duplicating the entire object it represents.



Modern Earth-field schematic and historical magnetic-sphere diagram

1620: Bacon and organized inquiry

Francis Bacon argued for disciplined observation and experiment instead of hasty generalization.

His ant, spider and bee comparison asks how collecting facts and constructing explanations should work together.

He also imagined inquiry as organized work supported by institutions. Method and social organization belonged together.



Francis Bacon

1637: Descartes and reasoning

Descartes sought a reliable foundation for knowledge: “I think, therefore I am.” He emphasized orderly mathematical reasoning.

Analytic geometry linked algebraic relationships with geometrical problems.

Experiments and reasoning did not form two completely separate camps. Different investigators combined them in different ways.



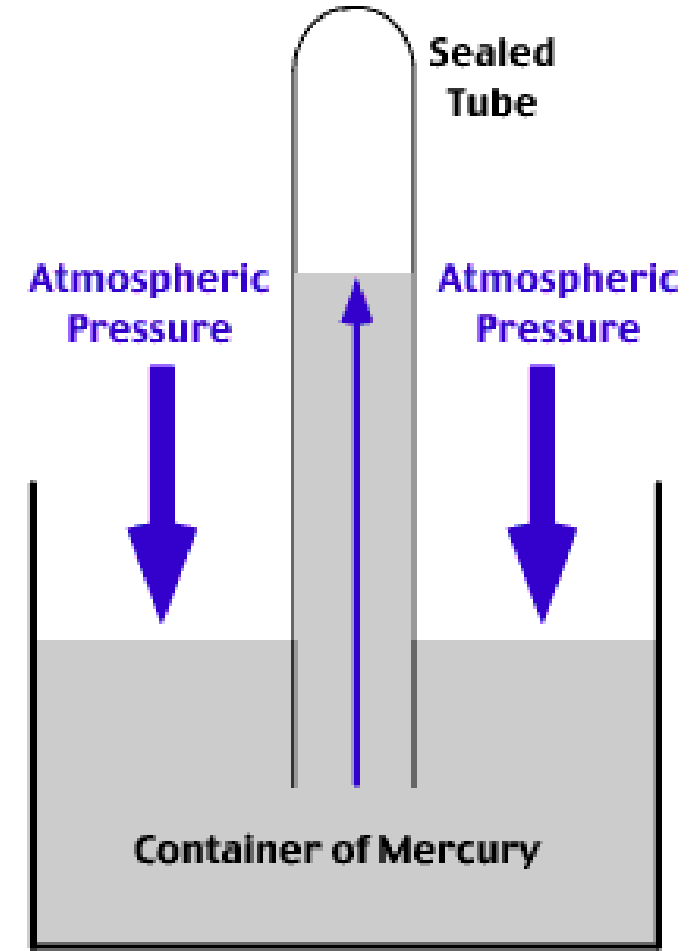
René Descartes

1644: Torricelli and air pressure

An inverted mercury-filled tube leaves a space above the column while mercury remains supported in the tube.

Torricelli argued that the weight of the surrounding air supported the column.

The experiment made an invisible influence investigable through a visible height. Apparatus turned an argument into a test.



Mercury-column arrangement and atmospheric pressure

1648: Pascal's altitude test

Pascal proposed comparing the mercury column at different elevations. Florin Périer carried out the mountain observations.

The column was lower higher on the mountain, consistent with less atmosphere pressing above the instrument.

A strong test changes a condition for which the explanation predicts a difference. This extends the brief Lecture 1 example.



Later representation of the mountain barometer experiment

Boyle, Hooke and the air pump

Air-pump experiments depended on making equipment work reliably enough to support a claim.

Boyle and Hooke's work joined experimental questions with the skill required to build and operate apparatus.

Witnesses, written descriptions and repetition helped a result travel beyond one room. These are the conditions behind our opening painting.



Robert Boyle

Pressure and volume

For a fixed amount of gas at approximately constant temperature, pressure and volume vary inversely.

If volume is halved under those conditions, the idealized prediction is that pressure doubles.

The conditions matter. Heating the gas or allowing it to escape changes the problem. A law needs a stated range of application.

1660: a society for inquiry

The Royal Society brought people together to observe, demonstrate and discuss natural phenomena.

Correspondence extended the conversation beyond weekly meetings. Experimental work depended on organizational labour as well as ideas.

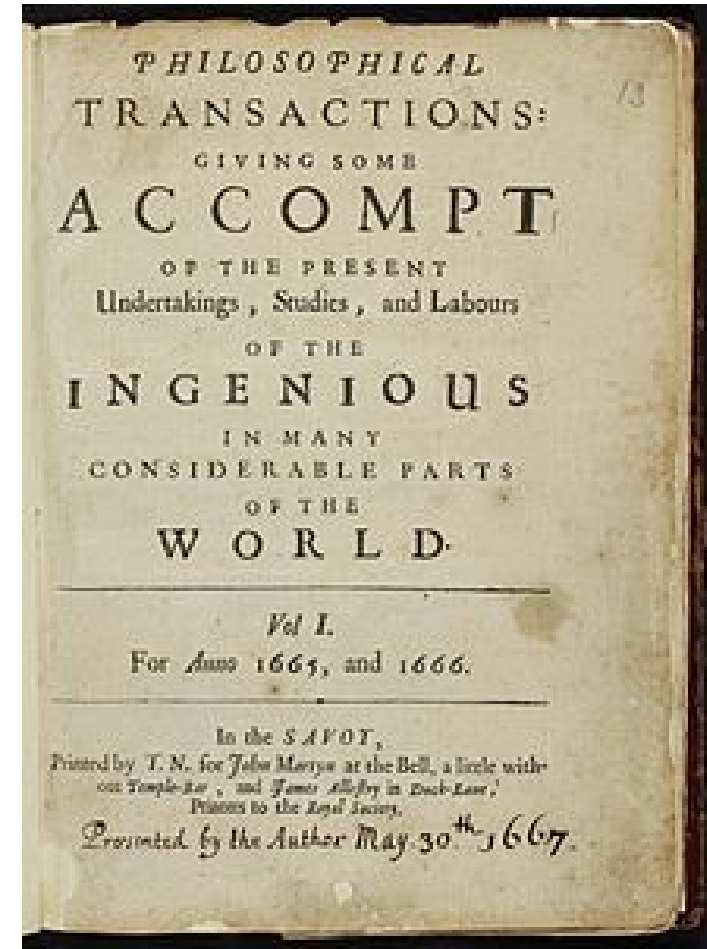
Its early members came from restricted social groups. An institution can widen collaboration while still excluding many people.

1665: scientific periodicals

Henry Oldenburg launched Philosophical Transactions in 1665, drawing on correspondence and reports.

A periodical made findings available in installments rather than only in a completed book.

Publication helped establish priority and invite scrutiny. The early journal's editorial practices differed from modern peer review.



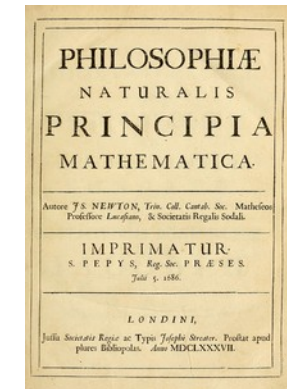
Title page of Philosophical Transactions

1687: Newton's synthesis

The Principia joined laws of motion with universal gravitation in a mathematical account.

The same framework could connect motion near Earth with planetary motion.

This synthesis drew on earlier problems, observations and mathematics. Newton's achievement did not remove the need for further testing.



Newton and the title page of the Principia, 1687

A law with a stated meaning

In modern notation, force describes the rate of change of momentum. For constant mass, this becomes $F = ma$.

A larger net force produces a larger acceleration for the same mass.

The notation summarizes a relationship. It does not replace identifying the body, the forces and the assumptions of a problem.

$$\mathbf{F} = \frac{d}{dt} (m\mathbf{v})$$

Modern momentum form of Newton's second law

The wider seventeenth-century community

Hooke investigated small-scale structures and designed experiments. Huygens worked on motion, light and timekeeping.

Halley supported the publication of Newton's Principia. Leibniz developed calculus through a distinct mathematical programme.

A scientific transformation depends on interacting contributions, even when a few names dominate later accounts.

18th century: Enlightenment

Enlightenment writers examined inherited authority and debated reason, liberty and religious toleration.

They disagreed about the foundations and limits of knowledge, as well as about political change.

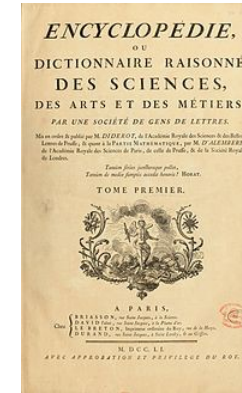
The movement was broader than science and never a single programme accepted by everyone.

1751–1772: the Encyclopédie

Diderot and d'Alembert directed a collective project bringing sciences, arts and trades into an organized reference work.

Its original series comprised 17 text volumes and 11 volumes of plates.

The scope made practical skills visible beside learned subjects. Producing such a work required writers, artisans, editors and publishers.



Title page and open volume of the Encyclopédie

Knowledge made visible

The frontispiece represents truth through light and the lifting of a veil.

This is a symbolic statement about the pursuit of knowledge, rather than evidence for a scientific claim.

Illustrations elsewhere in the work could explain tools and processes. Images could both teach and persuade.



Frontispiece of the Encyclopédie, 1772

The Encyclopédie encountered censorship and restrictions, yet publication continued through complex arrangements and support.

Books and journals needed money, permissions, distribution and readers.

Public reasoning therefore depended on material and political conditions as well as the strength of an argument.

Salons and public conversation

Salons, coffeehouses, academies and print created different settings in which ideas could circulate.

Hosts, translators and readers helped shape intellectual life even when they held no formal scientific office.

Participation remained unequal. Ask who could enter, speak, publish or afford to read.



Lemmonnier's later representation of a reading in Geoffrin's salon

1784: Kant and public reasoning

Kant urged people to use their own understanding rather than depend uncritically on others.

He defended the freedom to address a reading public with reasons and criticism.

His distinction between public reasoning and duties within an office complicates a simple slogan of unrestricted disobedience.

Beantwortung der Frage: Was ist Aufklärung?

„Aufklärung ist der Ausgang des Menschen aus seiner selbst verschuldeten Unmündigkeit. Unmündigkeit ist das Unvermögen, sich seines Verstandes ohne Leitung eines andern zu bedienen. Selbst verschuldet ist diese Unmündigkeit, wenn die Ursache derselben nicht am Mangel des Verstandes, sondern der Entschiedenheit und des Muthes liegt, sich seiner ohne Leitung eines andern zu bedienen. Sapere aude! Habe Muth, dich deines eigenen Verstandes zu bedienen! ist also der Wahlspruch der Aufklärung.“

„Saulheit und Feigheit sind die Ursachen, warum ein so großer Theil der Menschen, nachdem sie die Natur längst von fremder Leitung frei gesprochen (conversare sibi libere), dennoch keine Zeitwendig unumündig bleiben; und warum es Andern so leicht wird, sich zu deren Vorurtheilen aufzuwerfen. Es ist so bequem, unumündig zu seyn. Habe ich ein Buch, das für mich Verstand hat, einen Geistlichen, der für mich über alles weisend hat, einen Herrn, der für mich die Zeit bezeugt, u. s. w., so brauche ich mich ja nicht selbst zu bemühen.“



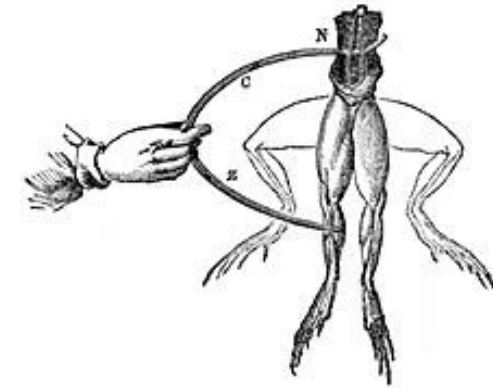
Kant's essay and portrait

Late 18th century: Galvani

Electrical stimulation made prepared frog muscles contract, raising questions about electricity and living tissue.

Galvani interpreted such observations through animal electricity.

The response was observable; its cause remained a subject of dispute. Competing explanations suggested different experimental arrangements.



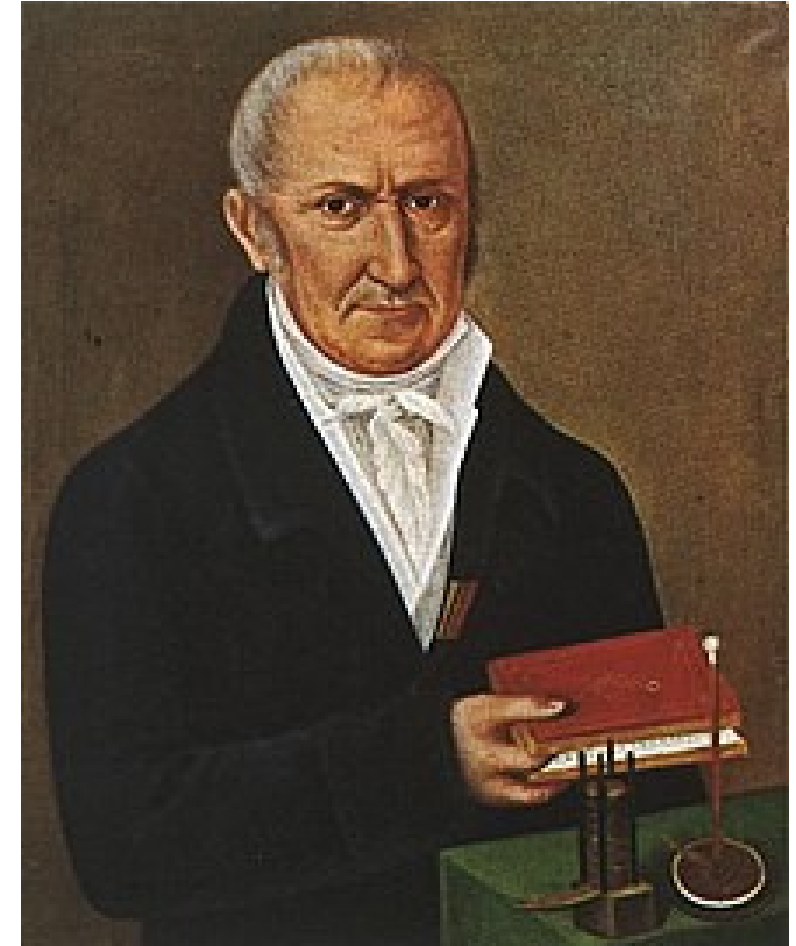
Frog preparation and an electrical detector diagram

1800: Volta's pile

Volta assembled different metals with moist separating material to produce a continuing electrical effect.

The pile showed that an electrical source could be made without animal tissue.

It did not show that living bodies have no electrical processes. A successful alternative can settle one claim while leaving another open.



Alessandro Volta with an electrical pile

Demonstration, recognition and patronage

The later image of Volta demonstrating before Napoleon connects a technical result with public recognition and political power.

A demonstration may attract support, but impressive performance and adequate evidence are separate questions.

Return to the opening audience: what should an informed witness ask before accepting the explanation?



Later representation of Volta's demonstration to Napoleon in 1801

What changed across these centuries?

Instruments made new phenomena accessible, and mathematical models connected observations.

Print and institutions gave people ways to communicate, compare and challenge results.

Access and authority remained contested. The history combines changes in ideas with changes in who could work and be heard.

Discussion: a spectacular new instrument

Imagine a patron funding a powerful instrument while allowing only a small invited audience to see its results.

What would make its claims credible beyond that audience? What might limit lasting progress?

Consider independent checks, detailed records, skilled successors and freedom to raise objections.

Funding can make an instrument and sustained work possible. Demonstrations can attract attention and teach observers.

Credibility grows when others can inspect methods, compare records and repeat relevant checks.

Restricted access may protect status while limiting criticism and training. A convincing public event is one stage of inquiry, not its completion.

Review questions

Why did printing matter without automatically making knowledge reliable or equally accessible?

What did the phases of Venus establish, and what did they leave undecided?

How did academies and journals change the conditions under which a claim could be challenged?

Repeated copies enabled shared discussion, but also spread errors. Literacy, price and censorship affected access.

Venus's phases challenged the traditional Ptolemaic arrangement. They did not alone distinguish Copernicus from Tycho.

Meetings, correspondence and journals widened scrutiny and preserved records. Participation and the quality of checking still varied.

Next: Ottoman institutions and choices

Lecture 5 returns to overlapping centuries in Ottoman history, examining learning and practical needs in their own settings.

We will compare institutions, translation, printing and educational change.

Keep the same question in view: what conditions allow a society to sustain and extend knowledge?

Reference: crisis and chronology

The Black Death caused profound disruption in fourteenth-century Europe.

The picture is a later representation of death, not a record of scientific activity ending in 1348.

A historical explanation needs to distinguish a severe crisis from a universal stopping point.



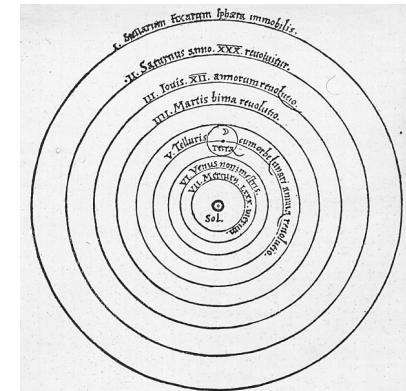
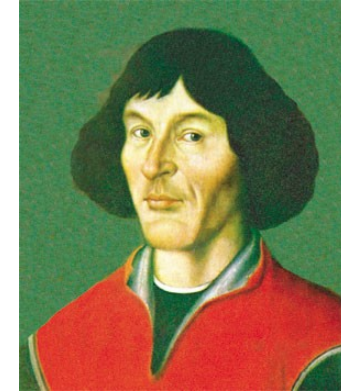
A later European image of death and destruction

Reference: Copernicus in two depictions

Portraits and planetary diagrams serve different purposes: remembrance and explanation.

Compare the planetary arrangement here with the version in the main discussion.

The differences between reproductions remind us to inspect the actual diagram and its labels.



Copernicus portrait and planetary diagram

Reference: Copernicus in context

The educational itinerary places Copernicus in several European centres of learning.

The accompanying list points to interests beyond astronomy, including questions about money.

Similar constructions appear in earlier Islamic astronomy. Their transmission to Copernicus remains debated.

University of Kraków (1491–95)

University of Bologna (1496–1500)

University of Padua (1501–03)

University of Ferrara (DCanL, 1503)

Heliocentrism

Quantity theory of money

Gresham–Copernicus law

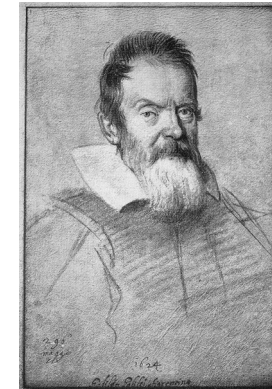
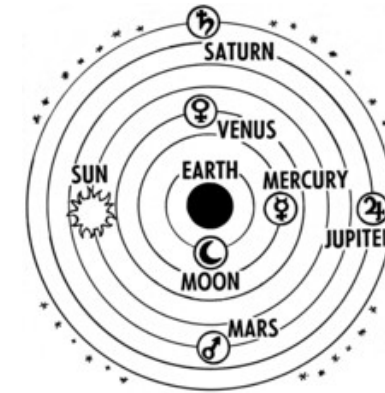
Copernicus: education and other interests

Reference: images of astronomy

The schematic compresses a model of the cosmos. Its ordering and omitted motions need scrutiny before using it for prediction.

The portrait commemorates Galileo, while a model diagram makes a claim about relationships.

Neither picture alone establishes the correctness of an astronomical theory.



Simplified astronomical schematic and Galileo portrait

Reference: conflict in later images

The woodcut and cartoon use dramatic scenes to frame a relationship between authority and inquiry.

Galileo's documented sentence was house arrest. The execution scene does not depict his fate.

Read the cartoon as satire. An image's emotional force is not evidence for its implied historical claim.



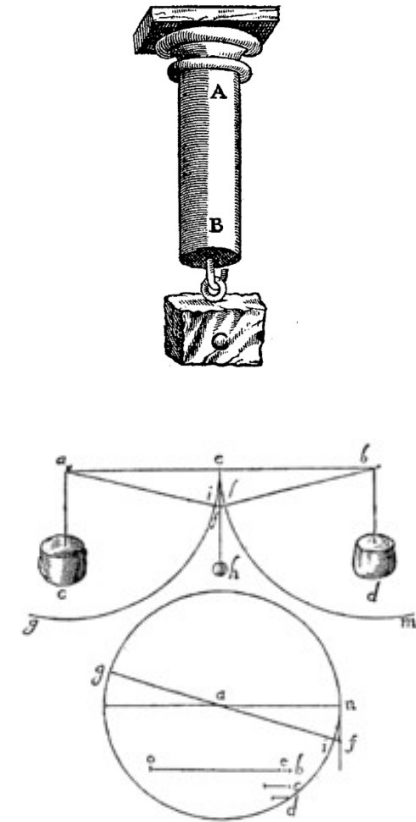
Execution imagery and a modern Galileo cartoon

Reference: Galileo's diagrams

The diagrams accompany investigations of material strength and motion.

Geometry makes assumptions and relations explicit, but interpreting a diagram requires its argument.

These are optional details for examining how a mathematical text presents a physical problem.



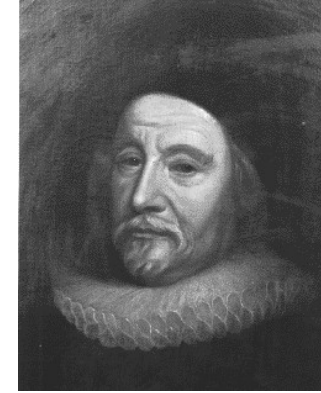
Diagrams associated with Two New Sciences

Reference: chronology and belief

Ussher used scriptural and historical chronology to date creation to 4004 BCE.

Such a chronology relies on different evidence and assumptions from geological dating.

Religious commitments also motivated inquiry. The picture of learned court life illustrates another social setting for philosophy.



Ussher portrait and a later representation of learned court life

Reference: John Ray and living things

John Ray connected the study of organisms with natural theology.

Classification and attention to form and function helped organize knowledge of living things.

The later histories of deep time and evolution extend beyond this lecture. They should not be read backwards as beliefs already held by these investigators.



John Ray

Reference: Torricelli in representation

The later image places the mercury experiment within a memorable scene.

Compare that scene with the main lecture's apparatus diagram: one stages an event, the other explains a relationship.

Dates and measured differences should come from records, not from visual storytelling alone.



Later representation of Torricelli's experiment

Reference: Newton and Cambridge

The portrait and college photograph connect an individual with an institutional setting.

Newton worked on optics and mathematics as well as motion and gravitation. His interests also included theology and alchemy.

A historical investigator's interests do not always match our modern disciplinary boundaries.



Newton portrait and Trinity College, Cambridge

Reference: mechanisms and makers

A modern hand-operated winch helps us recognize how rotation performs useful work.



Böckler's illustrated machinery belongs to a tradition of making mechanisms available through books.



A modern analogy explains a principle; it does not establish the first date of a historical invention.

Modern winch and portrait associated with Böckler

Reference: remembering Galvani

A monument makes an investigator part of public memory.

The frog experiments are remembered for opening questions about electricity and physiology.

Commemoration is different from reconstructing exactly who observed each result and how the explanation developed.



Monument to Luigi Galvani

Sources for further study

Museo Galileo and Stanford Encyclopedia of Philosophy: instruments, Galileo, methods and Enlightenment.

National Library of Medicine, National Gallery and Royal Society: bodies, demonstrations and scientific communication.

ARTFL Encyclopédie: the eighteenth-century collective work and its publication history.