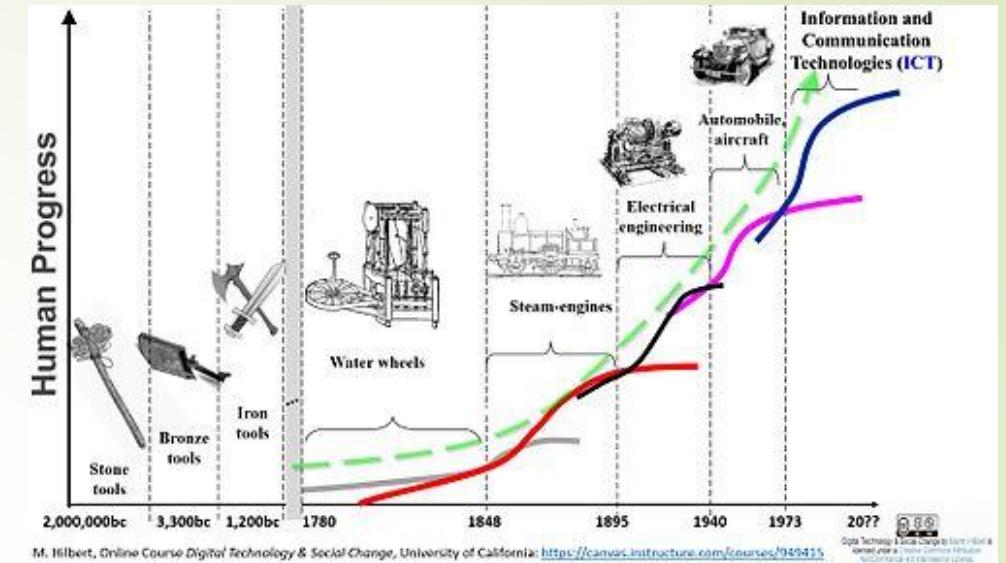


A brief (hi)story of science and technology

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Science vs. Technology

- ▶ Science: understanding universe, nature (driven by curiosity)
- ▶ Technology: tools to make life better (driven by needs of man)
 - ▶ Applied science, engineering, ...
- ▶ Usually, science leads to technology
 - ▶ Understanding Maxwell's electromagnetism lead to radio waves

Maxwell's Equations	Maxwell's Equations
Differential form	Integral form
$\nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0}$	$\oint \vec{E} \cdot d\vec{a} = \frac{Q_{enc}}{\epsilon_0}$
$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$	$\oint \vec{E} \cdot d\vec{l} = -\int \frac{\partial \vec{B}}{\partial t} \cdot d\vec{a}$
$\nabla \cdot \vec{B} = 0$	$\oint \vec{B} \cdot d\vec{a} = 0$
$\nabla \times \vec{B} = \mu_0 \vec{J} + \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t}$	$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc} + \mu_0 \epsilon_0 \int \frac{\partial \vec{E}}{\partial t}$



Science vs. Technology

- ▶ Technology can also develop before the corresponding science
 - ▶ Michael Faraday and others developed electric motor and generators before Maxwell's theory was developed
- ▶ Example: development of vaccines happened before the corresponding virus was understood fully or seen
 - ▶ Variolation in India/China for smallpox (effective but risk of complications)
 - ▶ Edward Jenner developed a better smallpox vaccine from cowpox pus
 - ▶ Louis Pasteur developed safe rabies vaccine from attenuated rabies virus

836

PASTEUR'S LATEST DISCOVERY.

FIVE years ago the great French chemist Louis Pasteur determined to find a remedy for hydrophobia. His discovery of a method of inoculation by which cattle and sheep were enabled to defy anthrax, or spleen fever, had led him to believe that a serum of rabies could be used in a similar way for the protection of human beings. In June, 1880, he announced the problem so far as the inoculation of dogs was concerned, but until October last was able to announce that by inoculation men could be protected. This announcement was made at a meeting of the French Academy of Sciences. M. Pasteur then had two patients under treatment. He now has more than seventy. His process is described as follows: A rabbit is inoculated with a fragment of spinal marrow taken from a rabid dog. Fifteen days the rabid becomes mad and dies. A second rabbit is inoculated with a bit of spinal marrow taken from the first, and the inoculation is repeated until no more rabbits have been used. With each successive inoculation the virus becomes stronger, and the period of incubation is shortened, until, in the case of the sixteenth rabbit, it may serve days. The chemist discovered some years ago, while experimenting with the virus of foot-and-mouth, that it could be weakened or attenuated only by exposure to dry air. Bits of marrow from the inoculated rabbits, graded with reference to the strength of the virus, are at the time of extraction, exposed to dried air in bottles. In this way M. Pasteur processes a supply of serum graded from a specimen that is so attenuated as to be almost powerless up to a specimen that is fresh and that will cause hydrophobia in an animal in seven days. The person who has been bitten is inoculated under the skin by means of a raving needle containing oxidized liquid in which a small piece of marrow has been dis-

HARPER'S WEEKLY.

VOLUME XXIX., NO. 1513.

solved. State narrow containing virus of the greatest attenuation is first used. Virus of greater power is used in successive inoculations, until at last the most powerful is introduced. By degrees the patient becomes accustomed to it, and M. Pasteur holds that after safely undergoing the last inoculation of the series the patient is proof against hydrophobia.

The name of the chemist's patients was Józef Meister, an Alsatian. He was bitten in July last. Professor Pasteur and his wife of Paris were of the opinion that he could not escape a terrible death, unless he should be saved by this process. In ten days he was inoculated thirteen times, and the virus used in the thirteenth operation was of the greatest strength. On account of the death of a rabid dog in seven days, but had no effect upon Meister. When the disease was made known to the Academy of Sciences the inoculation was the most talked of event of the year. In a great number of cases, however, rabies is developed within six months. Pasteur is so certain that his treatment will be effective if it shall be applied at any time before death that he does not appear. Four children living in Algiers were bitten on August 20. That the dog was rabid is proved by the fact that one of them died in October of acute hydrophobia, and the two who survived reached Paris on October 20, and were inoculated. They have recovered, and are said to be in good health.

Owing to the varying length of the period of incubation, numerous physicians are not ready to admit at present that the safety of the inoculation has been proved. They prefer to wait until time and numerous cases



M. Pasteur.
AN INOCULATION FOR HYDROPHOBIA.—FROM "L'ILLUSTRATION."

"An Inoculation for Hydrophobia—From *L'Illustration*,"
Harper's Weekly 29:1513 (December 19, 1885), p. 836.
Bert Hansen Collection, New York

Science vs. Technology

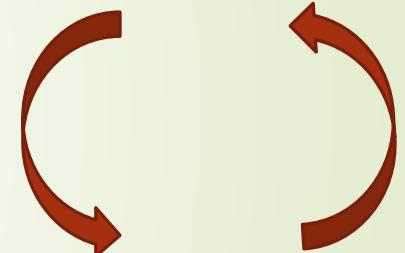
- ▶ Technology aids in the development of science
 - ▶ Telescopes helped develop modern astronomy
 - ▶ Microscopes helped develop germ theory of diseases



Science vs. Technology

- ▶ Scientific advances lead to better technology
 - ▶ But, when the conditions are right
- ▶ Technology can develop before science
 - ▶ Humans can engineer things without fully understanding the science behind it
- ▶ Availability of suitable technology critical to development of science
 - ▶ Modern science heavily depends on advanced experimental equipment

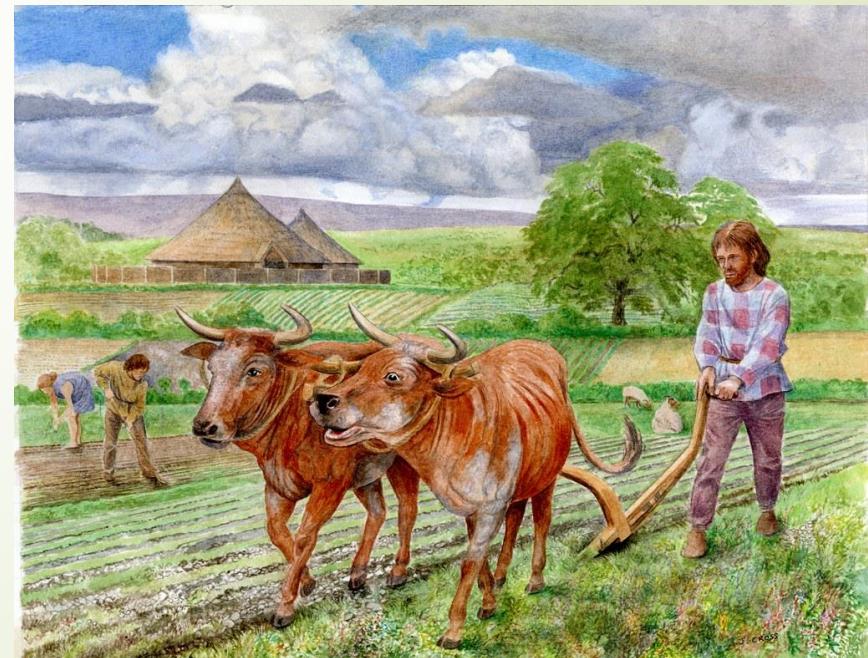
Science



Technology

Pre-history (Stone Age) Before ~3000 BC

- ▶ Pre-history: Before recorded history started ~3000 BC
- ▶ Hunter-gather societies with primitive tools evolved to agriculture-based societies
- ▶ Technology developed to make life better, inherent human nature to innovate
 - ▶ Improved agriculture and irrigation
 - ▶ Domestication of animals
 - ▶ Simple machines
 - ▶ Oral traditions and writing systems
 - ▶ Herbal medicines and simple remedies



Stone Age Science?

- ▶ What about science?
- ▶ Primitive theories of how nature works, mixed up with religion, incorrect by modern standards
- ▶ Observations of nature existed
 - ▶ Pre-historic Stonehenge (~3000BC) aligned with sunrise on summer solstice (some religious ritual?)



Ancient Civilizations (Bronze Age, Iron Age)

~3000 BC to ~500 AD

- ▶ Classical antiquity: large empires with extensive trade links



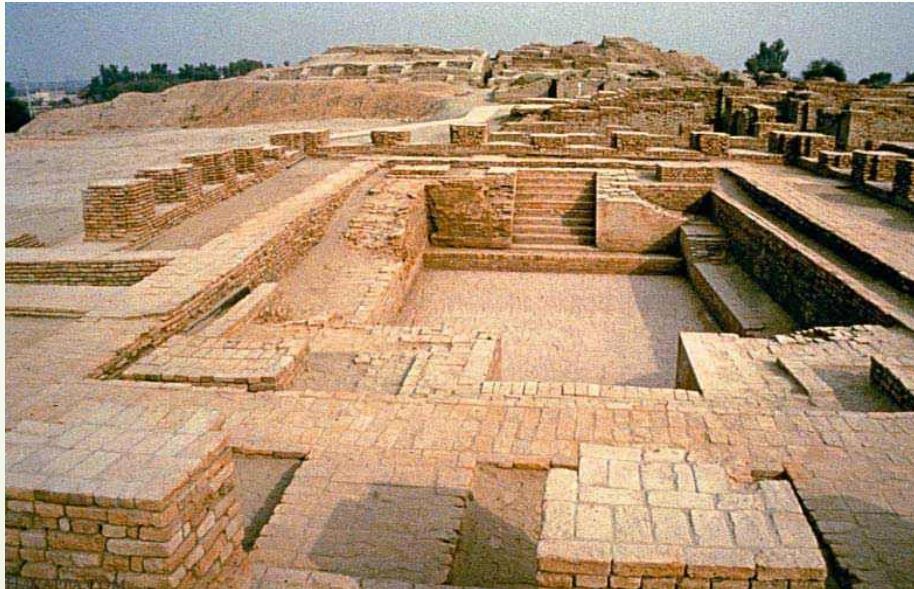
Technology in ancient civilizations

- ▶ Many tools for agriculture and trade (water mills, instruments, ships)
- ▶ Metallurgy, glass, soap, advanced knowledge of materials
 - ▶ Dancing girl of Harappa
 - ▶ Iron pillar of Guptas (no corrosion for ~1600 years)
 - ▶ Wootz / Damascus steel – very high quality to make weapons



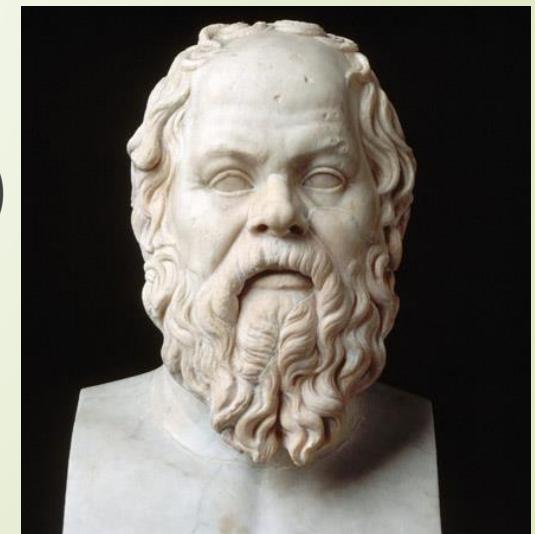
Technology in ancient civilizations

- ▶ Extensive knowledge of geometry and construction
 - ▶ Pyramids of Egypt
 - ▶ Great bath of Mohenjodaro, sewage system, standardized bricks
 - ▶ Roman aqueducts



Advances in ancient civilizations

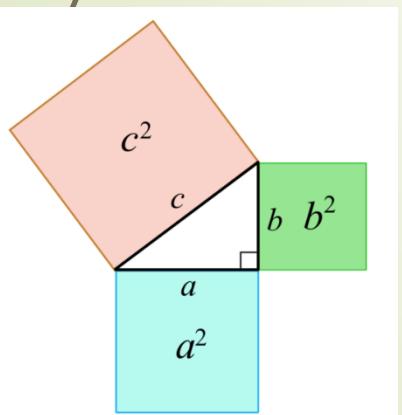
- ▶ Complex political theories: Greece, Arthashastra of Kautilya
- ▶ Simple medicine (Charaka, Hippocrates of Greece)
- ▶ Simple surgeries (Sushruta, Galen of Roman empire)
- ▶ Observation of plants and animals (Vedas, Pliny of Roman empire)
- ▶ Extensive literature, Panini's Sanskrit grammar
- ▶ Metaphysics and philosophy, several religions
- ▶ Indian and Greek schools of logic
 - ▶ Socratic method (asking and answering questions)
 - ▶ Plato, Aristotle and other great philosophers



Science in ancient civilizations

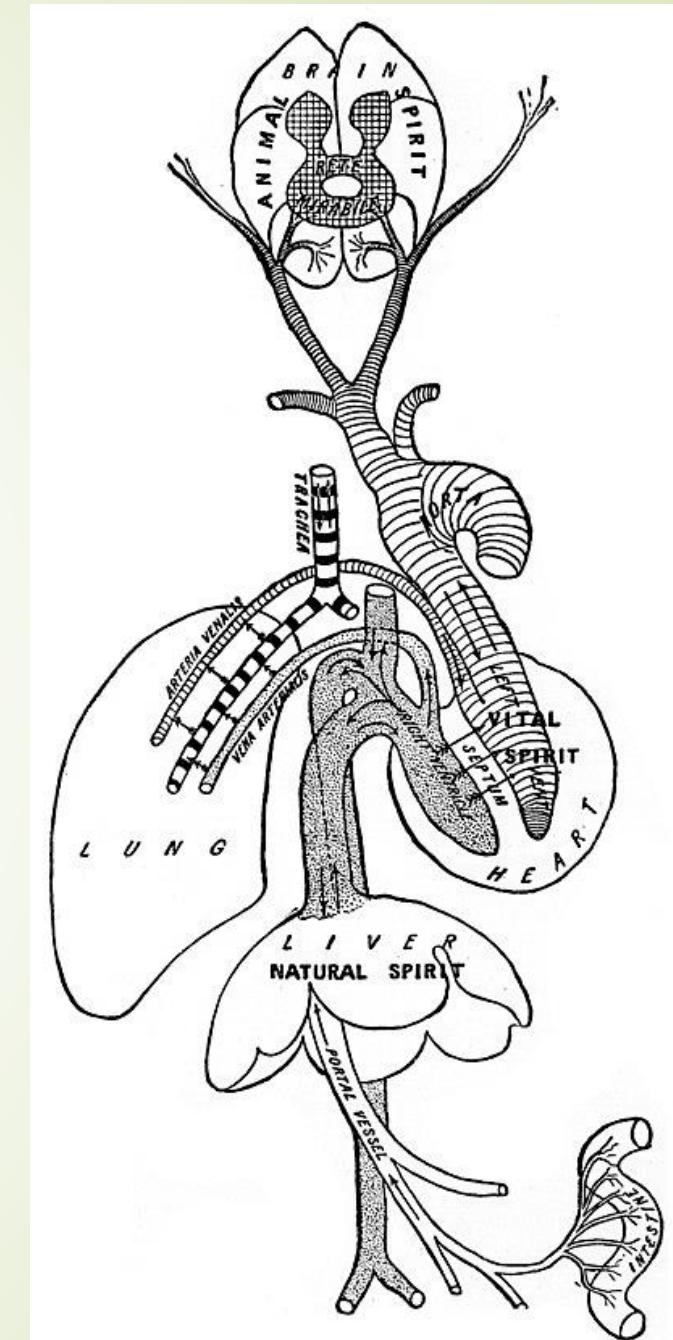


- ▶ Astronomical measurements (primarily for religious purposes and astrology)
 - ▶ Aryabhatta knew earth rotation, predicted eclipses
 - ▶ Eratosthenes of Greece measured circumference of Earth
- ▶ Number systems for calculations
 - ▶ Indo-Arabic numerals (zero, place value)
- ▶ Trigonometry and geometry
 - ▶ Approximation of pi
 - ▶ Pythagoras theorem known in Mesopotamia, India also
- ▶ Euclid of Greece: concepts of axiom, theorem, proof



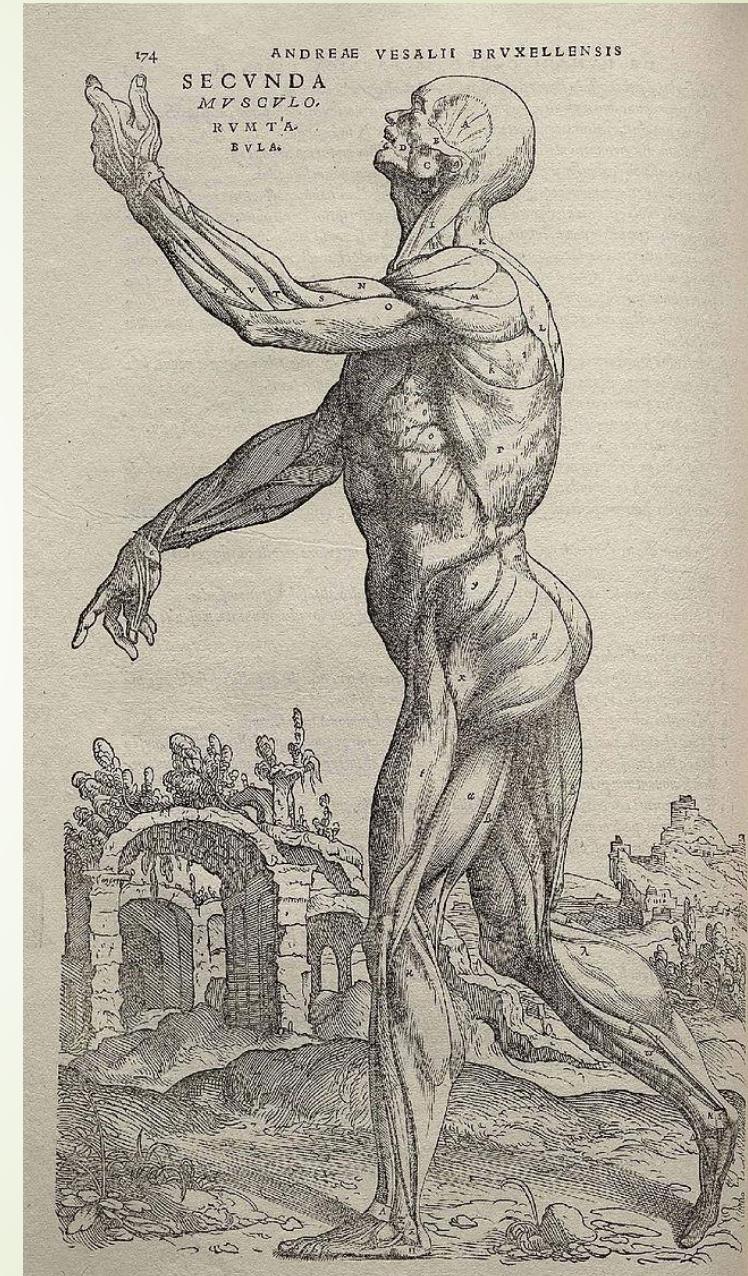
What was missing?

- ▶ Scientific theories were inaccurate by modern standards
 - ▶ Technology worked without knowing why it works
- ▶ Science was natural “philosophy”
 - ▶ Explanations about nature based on thought experiments
- ▶ Example: Aristotle’s physics
 - ▶ All matter made of four elements: earth, air, fire, water
 - ▶ All bodies move to natural state, so stone falls to earth
 - ▶ Heavier elements have more earth so fall faster
- ▶ Geocentric model of universe widely followed
 - ▶ Eclipses predicted but Rahu/Ketu based explanations
- ▶ Flawed theories of human body by Galen and others



Why inaccurate science?

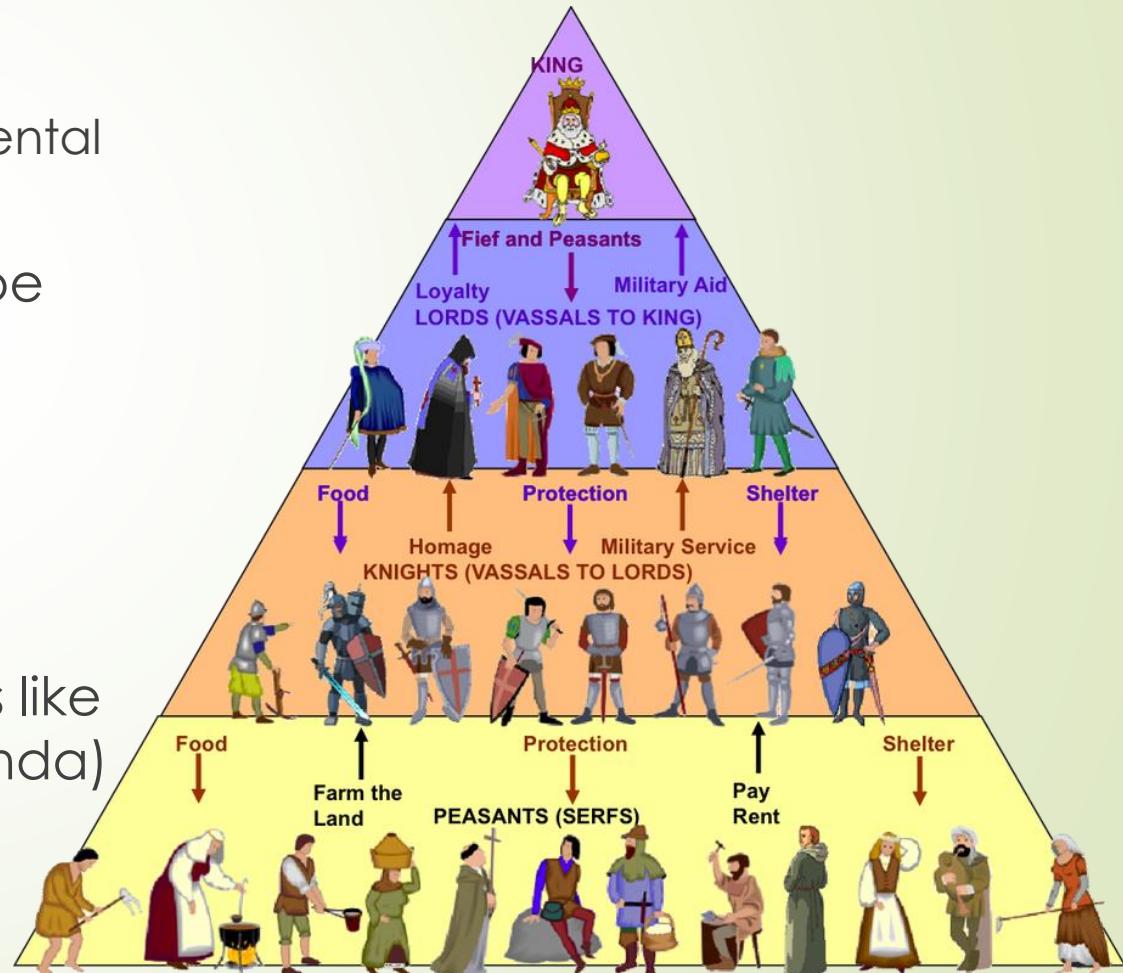
- ▶ Observations not the only way to understand nature
 - ▶ Religious authority was also basis for science, provided (mostly inaccurate) explanations for nature
 - ▶ Questioning authority discouraged (for social stability?)
- ▶ Culture (sanctity of life, impurity of corpses) prohibited some experiments like dissections
 - ▶ Founder of modern human anatomy Andrew Vesalius (16th century) said to have robbed graves
- ▶ Not enough technology available to enable scientific measurements, e.g., telescope, microscope
- ▶ Not enough skepticism: no one really asked 'how do you know'?



Middle Ages

~500 AD to ~1500 AD

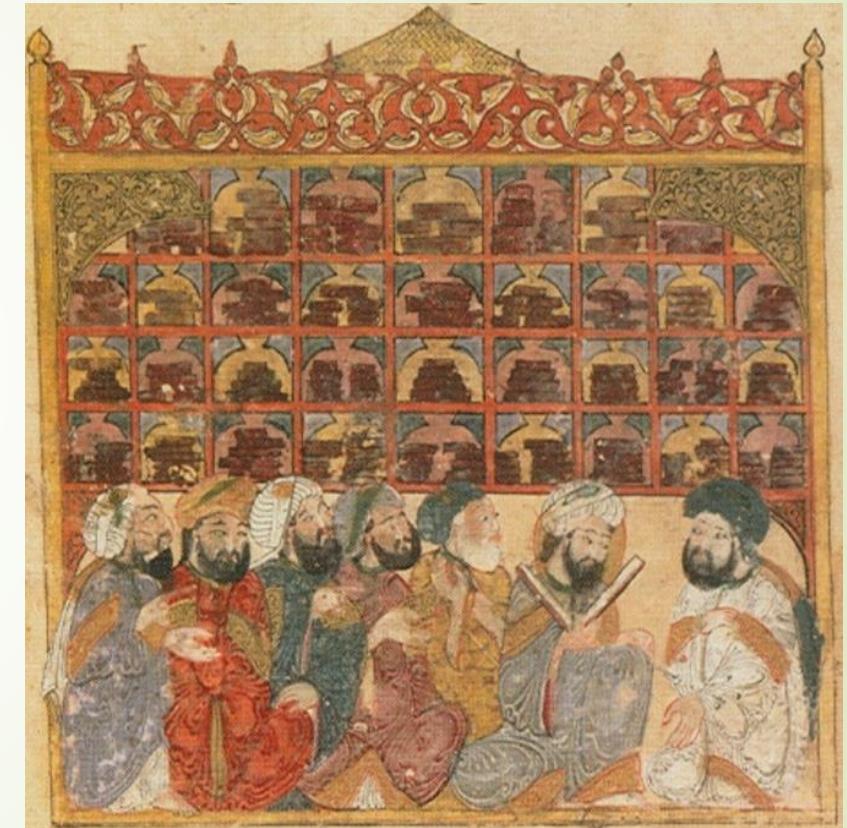
- ▶ Considered “dark ages” for science
 - ▶ No major breakthroughs, slow and incremental changes, life stayed more or less the same
- ▶ No large empires, political turmoil in Europe and rest of the world (including India)
- ▶ Conservative, hierarchical society
 - ▶ Feudalism in Europe
 - ▶ Caste system in India
- ▶ Science closely tied to religious institutions like Christian and Buddhist monasteries (Nalanda)
- ▶ Not suitable conditions for skepticism



Golden Age of Islamic Science

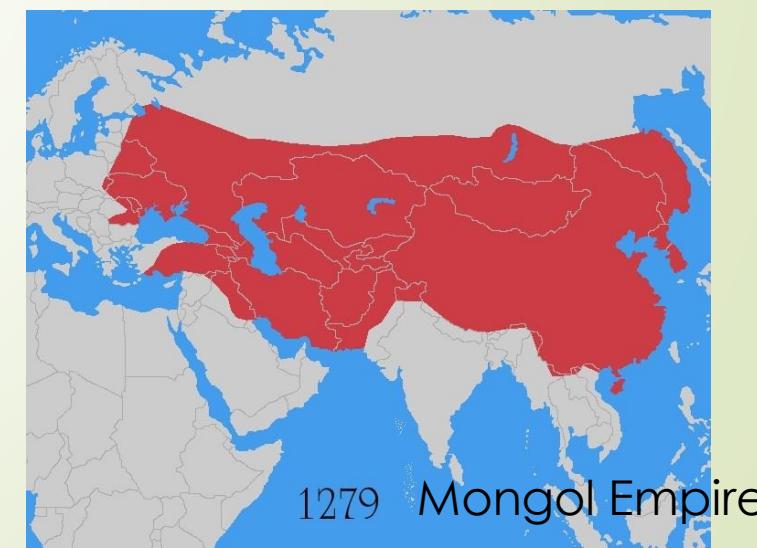
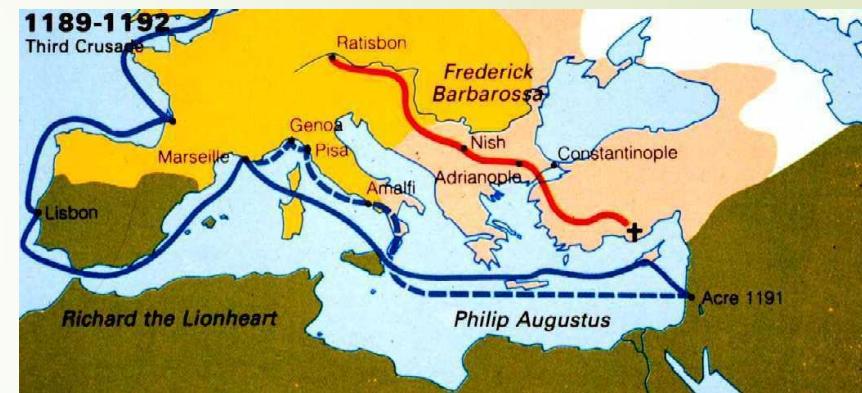
8th to 13th Century

- ▶ Rise of Islam and stable caliphates in Middle East: Islamic Golden Age
- ▶ Learned men from far and wide assembled at the House of Wisdom or Grand Library of Baghdad
- ▶ Translation and synthesis of classic Greek, Roman, Indian, Arabic science
- ▶ Major advances in astronomy, mathematics
 - ▶ Indo-Arabic numerals popularized
- ▶ Eastern Europe and Asia lead the development of science and technology



End of Middle Ages East meets West

- ▶ Start of middle ages: fall of Roman Empire, actions shifts to the East (Byzantine Empire)
- ▶ 1453: Fall of Constantinople (Byzantine Empire) to Ottomans, action shifts to Western Europe
- ▶ Classic Greek/Roman/Arab/Indian science “rediscovered” by Western Europe
- ▶ Other causes for fusion of East and West
 - ▶ Rise of Islam, crusades to reclaim Holy Land by Christian empires
 - ▶ Mongol invasions under Genghis Khan



End of Middle Ages Age of Discovery

- ▶ Columbus discovers the New World (Americas) in 1492, unknown to Europe until then
- ▶ Vasco da Gama discovers sea route to India in 1498, greater access to Asia
- ▶ What triggered the explorations?
 - ▶ Lucrative East-West trade controlled by Arabs, Italians (Silk Road)
 - ▶ Western Europe wanted to get into the action and started exploring
 - ▶ Church and Kings encouraged as a means to spread territory and Christianity
 - ▶ Better ships and compass technologies



Age of discovery European Imperialism

- ▶ Age of discovery marks start of European imperialism
 - ▶ Colonization of large parts of Americas, Africa, and Asia
- ▶ “Columbian exchange” of plants, animals, precious metals, resources, technology, diseases, ideas
- ▶ Europe races ahead to modernity, while the rest of the world is left behind
 - ▶ Many indigenous cultures wiped out by war, disease
 - ▶ Slave trade from Africas to Americas
 - ▶ Looting of gold and other resources from colonies
 - ▶ Gap between the developed / global north / first world and the developing / global south / third world persists even after end of imperialism



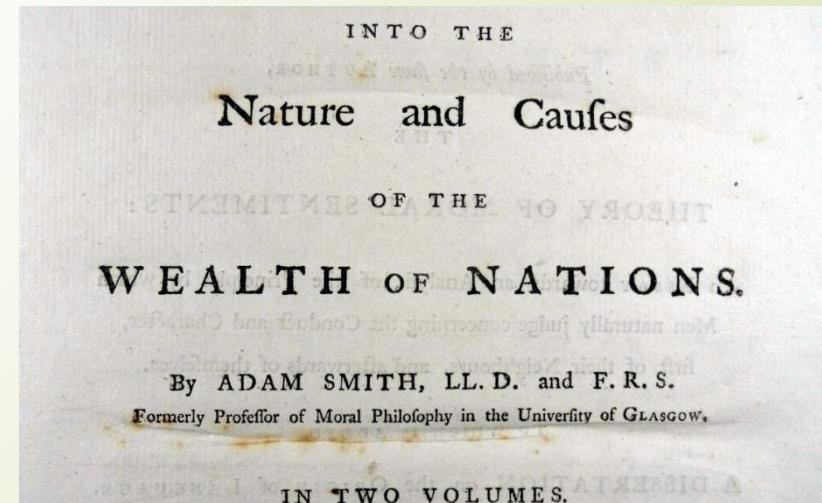
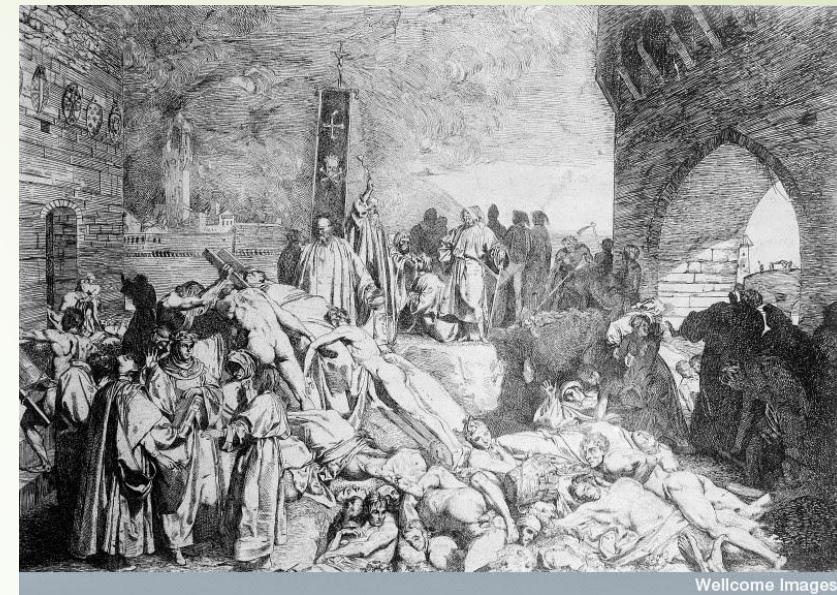
End of Middle Ages Societal changes in Europe

- ▶ Printing press (15th century) by Gutenberg
 - ▶ Able to transmit scientific/religious knowledge easily
- ▶ Protestant Reformation (16th century) by Martin Luther and others
 - ▶ Questioning the authority of the Catholic Church and its abuse of power
 - ▶ Everyone encouraged to read Bible for themselves
 - ▶ Martin Luther's German translation of the Bible widely printed and distributed
- ▶ Printing and Reformation reinforced each other, leading to better literacy for the common man



End of Middle Ages Societal changes in Europe

- ▶ 14th century: Black death (bubonic plague) originated in Asia and spread on Mongol empire routes via fleas on rats
 - ▶ Wiped out a third of Europe's population
 - ▶ Higher wages, better quality of life, for those left
 - ▶ Caused decline of feudalism
- ▶ Start of formal banking systems, capitalism
 - ▶ Church opposed lending money for interest (usury)
 - ▶ Capitalistic ideas from medieval Islamic empires
 - ▶ Adam Smith in Wealth of Nations argued that free markets are good for all





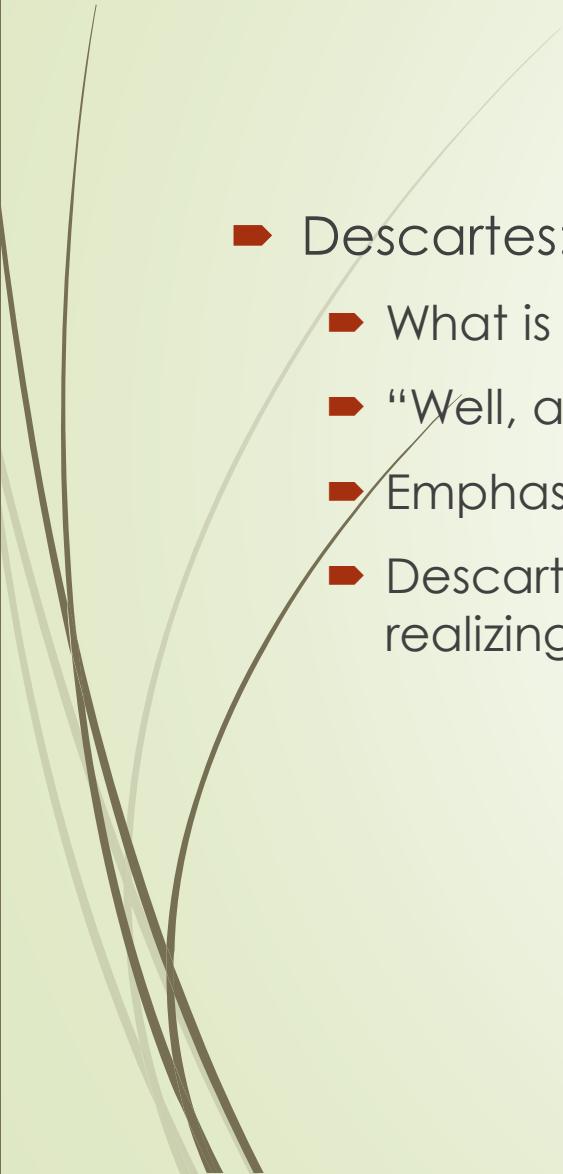
End of Middle Ages

A change in attitude?

- ▶ People started asking ‘how do you know?’
 - ▶ Man went from believing authority of ancient knowledge to questioning it
 - ▶ Greater reliance on experimentation and observations to formulate new theories
- ▶ What caused this change in attitude?
 - ▶ Cannot identify any one reason, can only guess probable causes in hindsight
- ▶ Discovering new worlds spurred doubt and skepticism?
 - ▶ Ptolemy thought Atlantic ocean till Asia, was proved false
 - ▶ Italian Amerigo Vespucci said after retuning from a voyage to the New World “Pliny did not touch upon a thousandth part of species of parrots, birds, animals of the new world”
- ▶ Greater literacy for the common man? Printing press?

Philosophers in the 16th century

- ▶ Descartes: Cogito ergo sum, I think (experience), therefore I am (I exist)
 - ▶ What is real? What is true? Do we always know reality? Are we brains in a vat?
 - ▶ “Well, at least I am thinking, so I exist”
 - ▶ Emphasis on thinking for yourself, knowing for yourself
 - ▶ Descartes not divorced from religion, only opposed religious authority (believed in realizing God on your own, “I can think of God so he must exist”)



Cogito ergo sum

Philosophers in the 16th century

- ▶ Francis Bacon: Observations are everything
 - ▶ Trust senses, do not trust theories with empty hypotheses
 - ▶ Purpose of science is to improve material condition of man
 - ▶ Inductive reasoning: collect facts and generalize
- ▶ John Locke: empiricism, liberalism
 - ▶ Empiricism: knowledge comes from sensory observations
 - ▶ Political philosophy of liberalism: each man has a natural right to seek life, liberty, property
- ▶ Fundamental change in thinking: Age of Reason
 - ▶ Primarily in Western Europe



Renaissance

15th Century around Italy

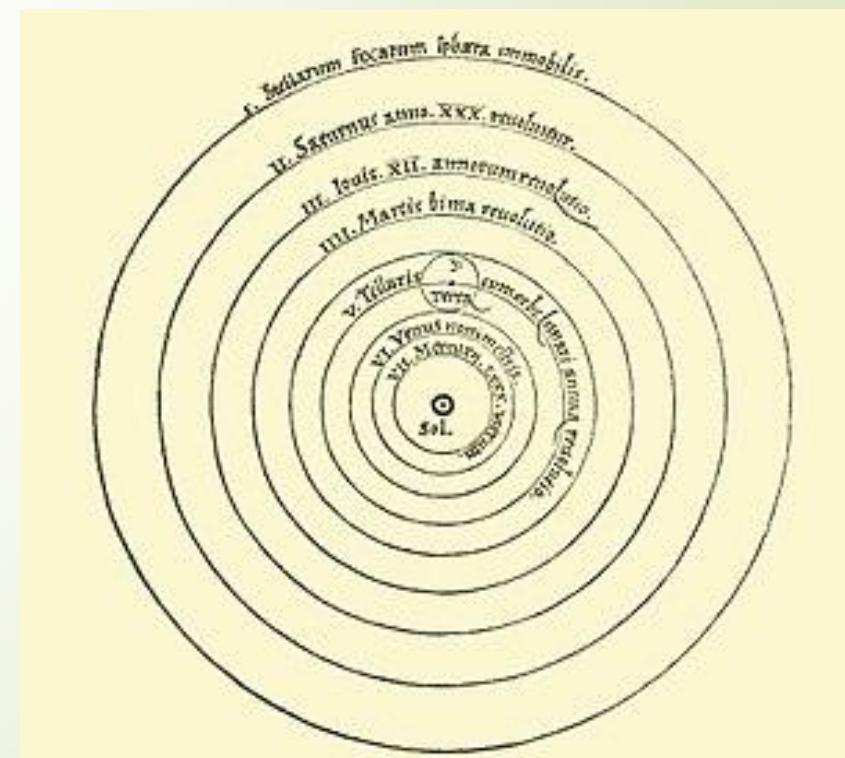
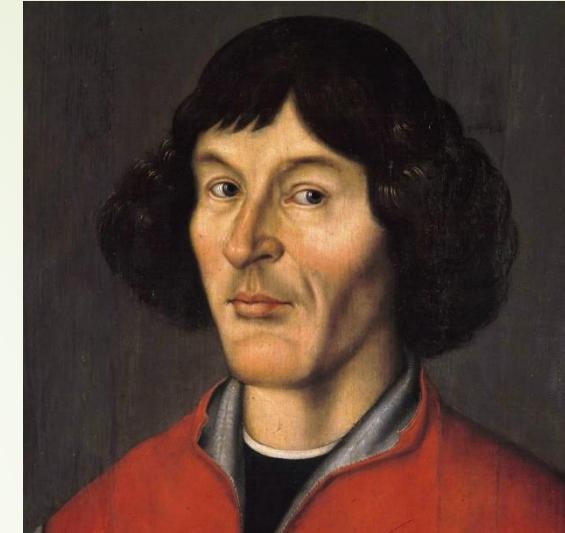
- ▶ Renaissance: revival of learning, arts and sciences
 - ▶ Primarily driven by flow of knowledge into Italy after fall of Constantinople
 - ▶ Rediscovery of classic Greek/Roman knowledge
- ▶ Impact easily seen in paintings
 - ▶ Pre-renaissance: mostly religious paintings without realism
 - ▶ Renaissance: realistic, better perspective (3D), foreshortening (oblique objects get shortened)
- ▶ Leonardo da Vinci's Mona Lisa is the most famous example



Scientific Revolution

16th, 17th century

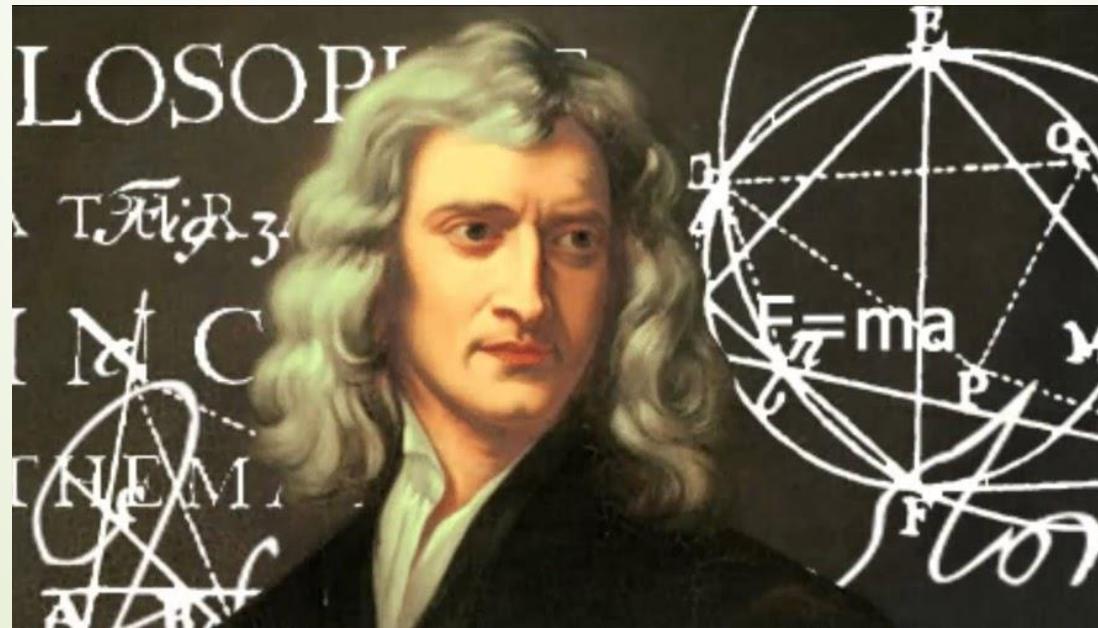
- ▶ Scientific revolution: birth of modern science, primarily in Western Europe
- ▶ Advances in science driven by empirical observations
 - ▶ Heliocentric model of the universe, by Copernicus, Brahe, Kepler, Galileo
 - ▶ Microscope, telescope demystify the world
 - ▶ Andrew Vesalius' work on the anatomy of the human body



Age of Enlightenment / Age of Reason

18th century

- Age of Enlightenment: Newton, Bacon, Locke are considered chief architects
 - Newton's laws of motion, law of gravitation, mechanistic explanation of universe, path of planets explained, calculus
 - Robert Boyle, Lavoisier (father of modern chemistry)



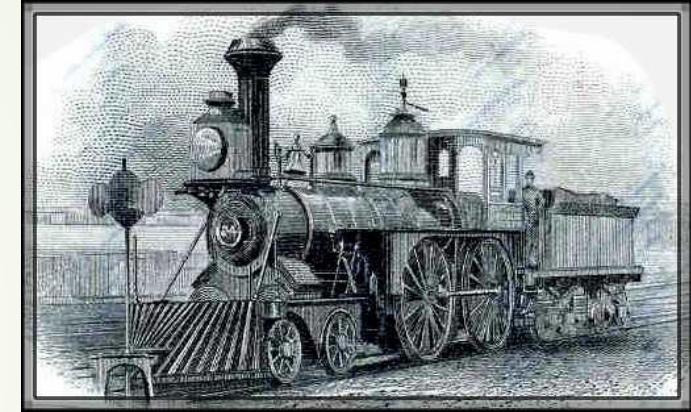
Enlightenment: Impact on common man?

- ▶ Newton was famous among a few rich men
 - ▶ “Nature and Nature’s laws lay hid in night, Then God said ‘Let Newton be!’ and all was light”
- ▶ But Age of Enlightenment didn’t touch the poor or women or the common man
 - ▶ Abstract concepts not of use to common man
 - ▶ Example: communication with dead has more appeal than law of gravitation
- ▶ Pushback on science that it was somehow diminishing the beauty of life, mystery of existence, moral values
 - ▶ Romanticism in 18th-19th centuries emphasized arts, literature, music, encouraged intense emotions, awe of nature

Industrial revolution

19th century

- ▶ Industrial age driven by engineers applying science to real life applications, mainly in Western Europe / USA
 - ▶ James Watt's steam engine started industrial revolution
 - ▶ Steam-powered locomotion, mechanized factories
 - ▶ Harnessing fossil fuels for energy
 - ▶ Electromagnetism (Michael Faraday, Maxwell's equations), electricity, light bulb (Edison), electric motors
 - ▶ Atomic theory (Dalton), periodic table (Mendeleev)
 - ▶ Darwin's theory of evolution
 - ▶ Germ theory linking microbes to diseases (Louis Pasteur)
- ▶ Great improvement in productivity, standard of living
- ▶ European technological supremacy furthers imperialism



Industrial Age

Impact on common man

- ▶ Initially industrial revolution caused poverty, people worked long hours in factories
 - ▶ Poet Blake called factories as “dark Satanic mills”
- ▶ By end of 19th century, life of common man began to improve
 - ▶ More productivity, more consumption
 - ▶ Better standard of living
 - ▶ Large cities, trades, ports
 - ▶ Electricity, lighting, transport
 - ▶ Greater wealth from imperialism
 - ▶ Better health and life expectancy



Industrial Age

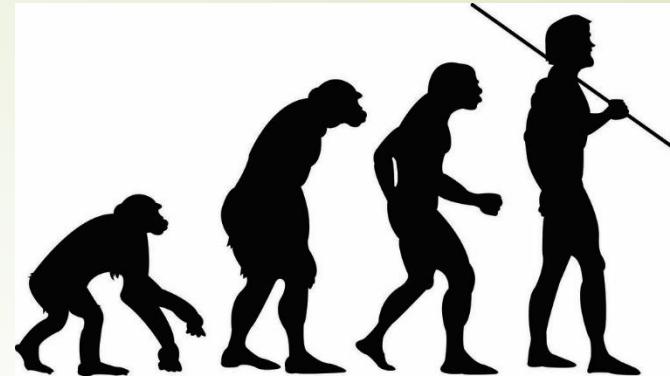
Scientific temper in common man

- ▶ Common man starts to see the benefits of modern science and technology
- ▶ Scientific temper in daily life
 - ▶ Common man starts to question authority, superstition
 - ▶ Primacy of individual, religious and political freedom
 - ▶ Demands of liberty, equality, justice
 - ▶ Reason not just a means for reaching truth, but a principle to be defended in daily life
- ▶ Public outreach of science via lectures and expos
 - ▶ Greater interactions between scientists and craftsmen
 - ▶ Grand international exhibitions of technology



Great exhibition, Crystal Palace
London, 1851

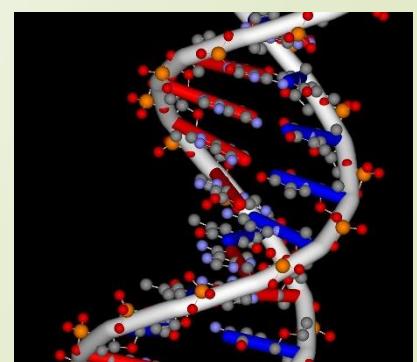
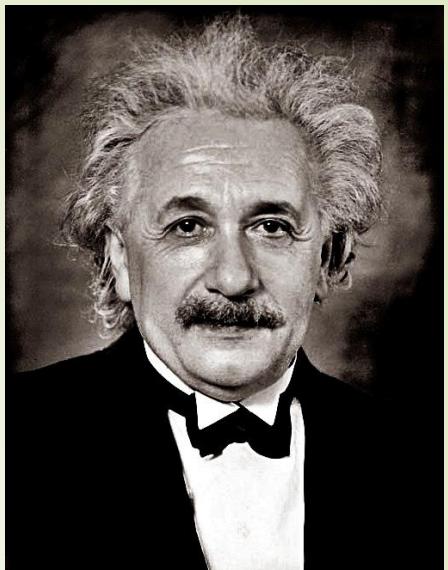
Impact on religion



- ▶ Newton's mechanistic universe dealt a blow to Church, Bible
 - ▶ Further blow by Darwin's theory of evolution
- ▶ Pushback from Church: reason cannot be used to explain Scriptures
 - ▶ Protestants questioned Catholics, but didn't support science (Martin Luther was opposed to Copernicus)
- ▶ A new view of God begins to emerge in 18-19th century: Deism
 - ▶ God created universe, which works according to scientific laws
 - ▶ God does not interfere, no moral demands as said by organized religion
 - ▶ People saw science as a way of understanding God and his universe
 - ▶ Scientists were religious too: science for the knowable, faith for the unknowable

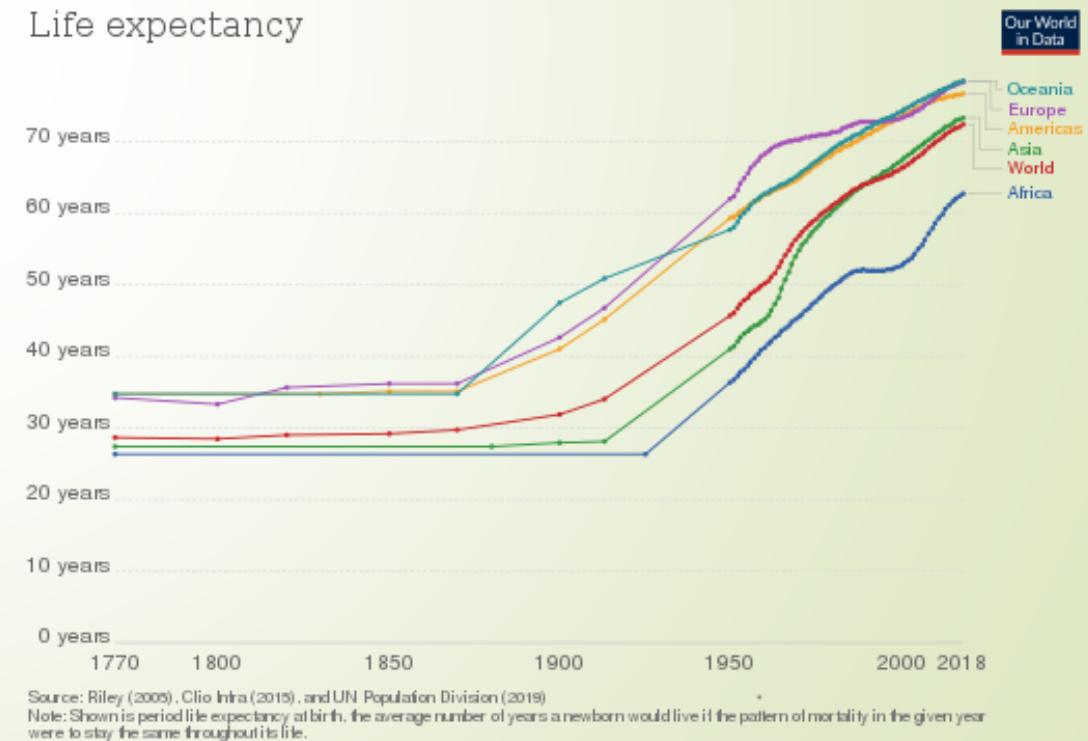
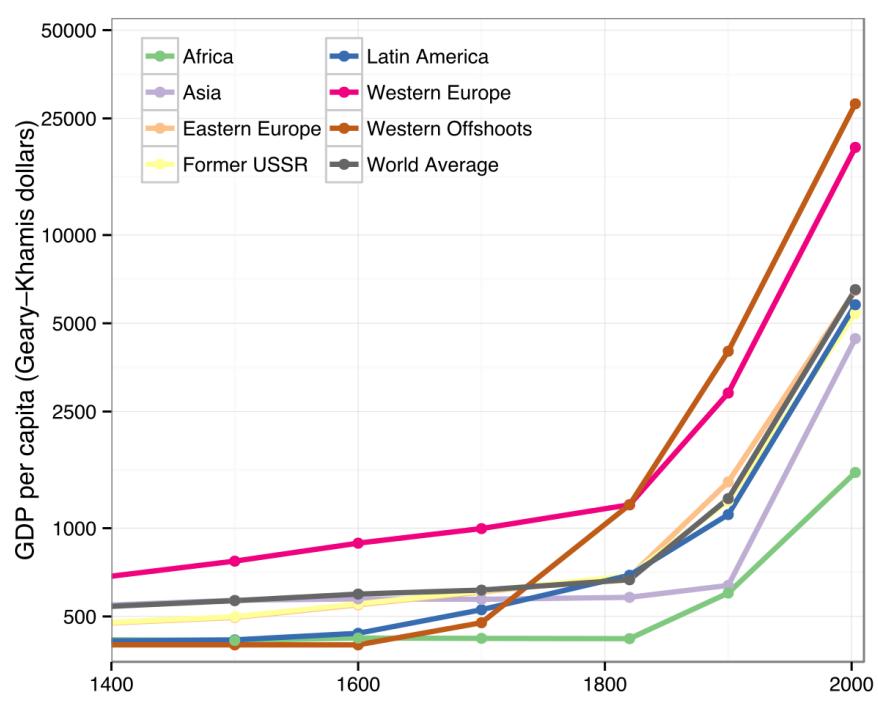
Modern Age 20th and 21st century

- ▶ Industrial age fuels imperialism, tensions between European imperial powers eventually culminate in two world wars
- ▶ Rapid progress of science and technology in 20th century
 - ▶ Einstein's theory of relativity, quantum mechanics
 - ▶ Radioactivity, atomic physics, atom bomb during WW2
 - ▶ Genetics: Watson and Crick model of DNA, human genome project
 - ▶ Medicine: antibiotics, vaccinations, eradication of polio & smallpox
 - ▶ Automobiles, airplanes, space exploration
 - ▶ Electronics, computer, telephones, TV, Internet, cellular phones
- ▶ End of imperialism, industrialization around the world



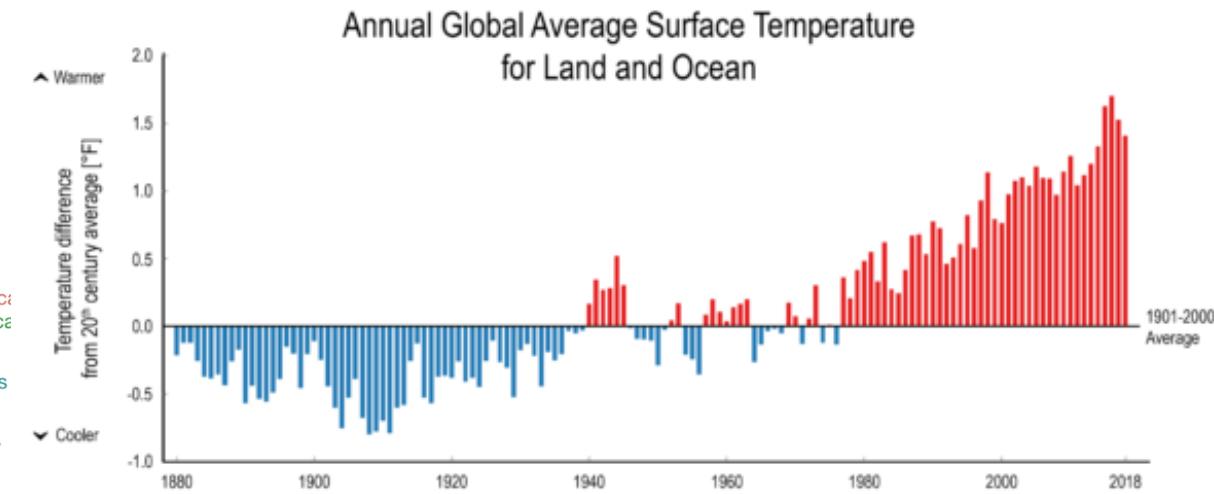
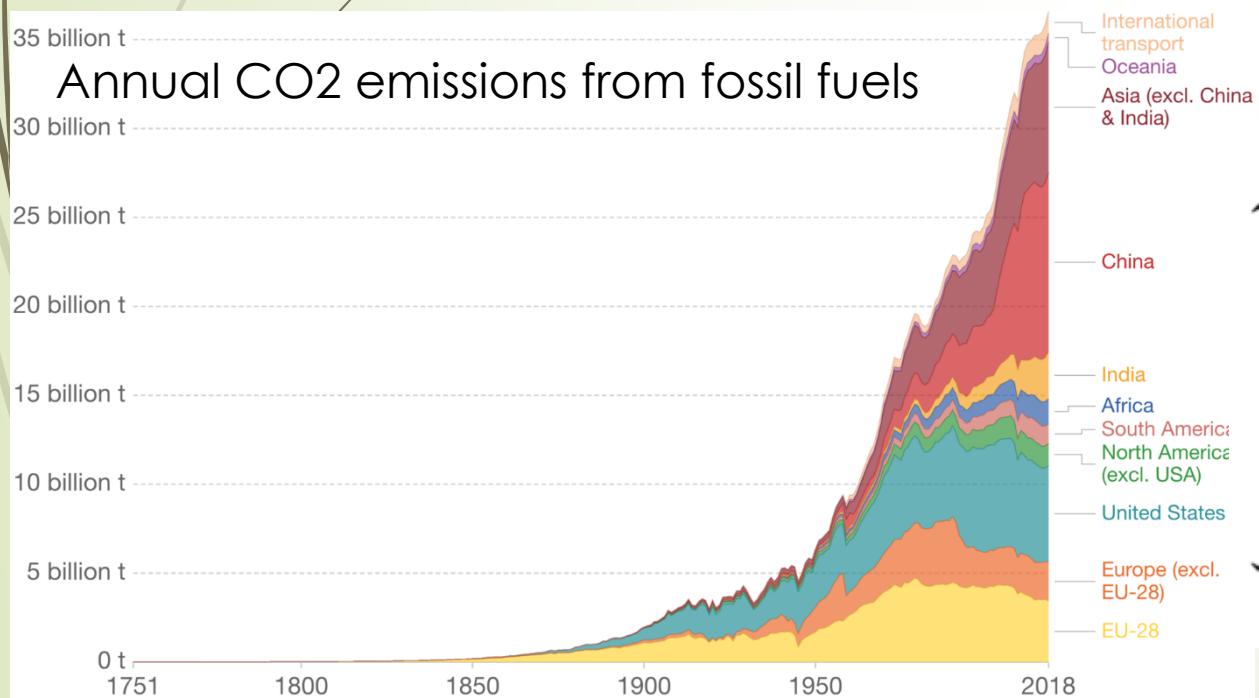
A great improvement in human lives

- ▶ Life of humans was more or less the same for thousands of years, and then it started to change drastically, starting in Western Europe
- ▶ More comforts, better health, more production and consumption of goods, higher standard of living



But all is not well

- ➡ Is everything better after the scientific revolution and industrialization? Or, are some things getting worse?
- ➡ CO₂ emissions which cause global warming are increasing rapidly
 - ➡ Rapid release of carbon in fossil fuels into atmosphere



Environmental impact of industrialization

- ▶ Excessive materialism, consumerism
- ▶ Harmful emissions of greenhouse gases and climate change: global warming, floods and droughts
- ▶ Air and water pollution, respiratory issues
- ▶ Excessive use of cancer-causing harmful chemicals
- ▶ Non-bio-degradable waste, plastics filling up earth
- ▶ Increased land use, reduced greenery and forests
- ▶ Extinction of several species of living things
- ▶ What else can you think of?



Have we gone too far?



- ▶ We have transitioned to a high impact life style, but do we need all this?
- ▶ Example: bottled water vs. regular water
 - ▶ Clean regular water is available with a little effort in most places where people reach for bottled water
 - ▶ Bottled water doesn't necessarily taste better or contain useful minerals
 - ▶ Direct costs of bottled water almost always higher than regular water
 - ▶ Indirect costs of bottled water MUCH higher (fossil fuels to manufacture the plastic, shipping costs, waste disposal of non-biodegradable plastic)
- ▶ Do we think of all the costs when we pick up a disposable bottle of water?
- ▶ Are we thinking through the impact of technology on our lives and on the environment? Is this way of progress sustainable?

Time to pause and think



- ▶ Modern science and technology has given us great benefits, but also comes with some costs
- ▶ What path should future science and technology take, such that we have a better balance between costs and benefits?
 - ▶ Sustainable development, without destroying nature and the living ecosystem that we are a part of
 - ▶ Low poverty, benefits of science and technology reach the needy at the bottom of the pyramid
 - ▶ Good health, clean air and water, no hunger, comfortable lives for all
 - ▶ Meaningful work for all, reduced inequalities, peace and justice
- ▶ Time to think about the path ahead, not run the rat race blindly

Sustainable development goals

- ▶ What can we do to make these goals more than mere slogans?
- ▶ Several practices of modern technology (e.g., planned obsolescence) are in direct conflict with SDGs





Next: evolution of science and technology

- ▶ Understand the process of scientific and technological progress, so that we can steer it towards a more sustainable direction
- ▶ Understand modern scientific method: more reliance on observations, less on authority
 - ▶ Technology always existed, but better scientific theories accelerated technology and improved daily life
 - ▶ New technology further enabled scientific development
- ▶ Why the sudden explosion of science and technology in the last 500 years? Why does progress happen in some places and times, and not in others?
 - ▶ Not just scientific method, but other societal factors contribute too
 - ▶ Society greatly influences the evolution of science and technology