Big Era Six
The Great Global Convergence
1400-1800 CE

Landscape Teaching Unit 6.6
The Scientific Revolution: What Changed?
1500-1800 CE

Table of Contents

Why this unit?

This unit examines the important changes in the theories and practice of science that took place in the 300 or so years centered on the seventeenth century. It is these changes, and their interaction with technology and with ideas about the universe and humans' place in it, that underlie almost every aspect of our lives today. Although rooted in earlier times, a new mindset developed during the scientific revolution and had far-reaching results. It validated and promoted:

- The use of reason
- The search for verifiable evidence
- The development of ways to confirm or disprove hypotheses
- The acceptance of the importance of mathematics for the study of nature
- The shift from an organic and personal to a mechanistic and impersonal view of the universe
- The concept of universal laws governing the behavior of physical matter
- The cross-fertilization between science and technology
- The role of science in gaining knowledge of practical use to humans.

The Scientific Revolution contributed to the rapidly increasing number and diversity of discoveries and inventions that transformed ways of thought and everyday life in significant ways.

The new science of the sixteenth through eighteenth centuries, however, was not an undiluted blessing. It enabled rapid progress in many areas. But it brought with it long-range problems as well as benefits. Scientific exploration was accompanied by changes in mindset that contributed to disturbing changes in society. It produced highly useful knowledge of the natural world, but, intertwined with new technologies, contributed to dangerously wasteful exploitation of natural resources. It laid the foundations for ways of preserving, extending, and increasing the comfort level of human life. But it also put into human hands the ability to destroy life, leading to atom bombs as well as to antibiotics. We are still facing issues connected with science that are rooted in its history.

Unit objectives

Upon completing this unit, students will be able to:

1. Clarify their ideas about the nature of science and identify historical changes in its theory and practice.
2. Identify, and compare, distinctive characteristics of science during the Middle Ages and during the sixteenth-eighteenth centuries (early modern period).

3. Describe changes and continuities in science from the tenth through eighteenth centuries; analyze the appropriateness of the label "Scientific Revolution."
4. Outline major historical developments that influenced science during the period covered in this unit.
5. Formulate a hypothesis, identify historical evidence relevant to the hypothesis, and revise it in view of the relevant historical evidence.

Time and materials

This unit is versatile. The variety and number of activities provided are meant to give teachers the choice to use those most suited to their interests and circumstances. Time taken will vary depending on how many activities are used and how long is spent on each one. Teachers may choose to assign Student Handouts as homework.

If the time available is severely limited, Lessons 1 and 2 are the core of the unit and can stand alone. They can be minimally covered in three class periods. Lesson 3 can be done in one additional class period. No materials are needed other than pencil and paper.

Author

Anne Chapman taught high school history for more than thirty years. She served as a history education consultant to the College Board, the Educational Testing Service, and the National Center for History in the Schools. She was a member of the National History Standards' world history task force. She wrote *Coping with Catastrophe: The Black Death of the 14th Century*, *Women At the Heart of War: 1939-1945*, and *Human Rights In the Making: The French and Haitian Revolutions* for the National Center for History in the Schools. She joined the World History for Us All team in 2001.

The Historical Context

From the Middle Ages on, and increasingly thereafter, individual European thinkers appropriated ideas and information from a wide variety of sources and applied them to many kinds of problems. Among the sources they drew on were Arabic translations of ancient Greek texts and original works by Muslim authors, rendered into Latin. Even among those European scholars who focused on the characteristics and operation of nature (as opposed to, say, theology or law), not all shared the same assumptions about how the world works, how we can discover how the world works, and how to approach Muslim or Greek ideas that appear to conflict with the Bible or with Christian doctrine. Science (called natural philosophy until well into the nineteenth century) was not a single unified idea. "New" and "old" ways of approaching nature coexisted at the same time.

Not only the information base but the mindset of educated Europeans underwent radical changes, centered on what is conventionally known as the scientific revolution of the seventeenth century.

Scholars disagree, however, on whether the term "revolution" is really appropriate. Some of the issues they have raised include these:

- The changes were set in motion by historical conditions and events that occurred in earlier centuries.
- Many medieval ways of thinking about the world continued to be influential as late as the eighteenth and nineteenth centuries.
- There was no agreement even among those engaged in science in the 1600's about which practices resulted in genuine knowledge. Some advocated reliance on reasoning one's way to theories (the deductive method, mostly associated with followers of Descartes and with continental practitioners). Others urged the primacy of collecting facts by observation and experiment (the inductive method, mostly associated with English scholars and followers of Francis Bacon.)
- The mathematization of science was an important feature of seventeenth-century scientific practice. But while some held that the purpose of science was to study the regularities observed in nature in order to establish mathematically formulated laws of nature, others aimed for knowledge of physical causes and doubted whether mathematics could capture the complexities and contingencies of nature.
- Two very different groups enlisted science in their cause: both radical freethinkers and those conservatives who held that finding universal laws in nature sanctioned the rule of law in society and guarded religious and moral principles against change,.
- The changes that occurred during the scientific revolution were far from pervasive. They continued to be resisted by a significant number of people working in the field of natural philosophy, as well as the general educated public. The new ideas left women and people below the upper middle classes virtually untouched before the eighteenthcentury.

Nevertheless, it would be hard to argue against the claim that by 1800 very basic changes had taken place in thinking about and observing the natural world, though changes came at different times in different places and were accepted in varying degrees. The following are some examples:

Astronomy. The picture of the universe changed from the medieval one, a universe enclosed within crystalline spheres to consideration of a plurality of worlds and the possibility of an infinite universe; and from belief in fundamental differences in the substance and behavior of matter on earth and in the heavens to knowledge of the universal laws of motion valid throughout the universe.

Anatomy. The authority of the Greek physician Galen was overturned as a result of Vesalius' hands-on dissection of human corpses, as well as Harvey's experiments in animal vivisection and measurement of the heart's capacity to pump blood.

Mathematics. Theory and practice changed from pre-1500 routine use of Roman numerals to full use of Indian/Arabic numerals with the zero, logarithms, coordinates, calculus, probability theory, and the slide rule.

Botany and zoology. Medieval classification of living organisms into four elements and four types of soul was replaced by Linnaeus' eighteenth-century classification by family relationships. According to him, he avoided classing humans with apes only to avoid "bringing down the theologians on my head."

Biology. The strongly rooted belief in spontaneous generation of worms, insects, and even rats from decaying matter, mud, or "ocean vapors" was disproved after 1600 by experimental investigation and microscopic examination of reproductive organs.

Chemistry. Alchemists in the Middle Ages recognized four elements: earth, water, air, fire. They attributed characteristics of living beings to minerals and attempted to transform base metals into gold. In the late eighteenth century, scientists issued a new table of 33 elements, separated air into several gases, decomposed water into newly-discovered oxygen and hydrogen, and generally abandoned the idea that the inorganic could be animate.

Pursuit of natural philosophy broadened. In the Middle Ages, it was almost exclusively the province of churchmen in universities. In the early modern period science in universities continued, but mainly non-church-related people pursued science in voluntary and government-sponsored scientific societies. Those who were not scientists but interested in, and knowledgeable about, science included even people of merchant and craft backgrounds, and, by 1800, women.

Before about 1500, Europe was a society that thought of itself as Christendom, with virtually universally accepted values, world-view and mindset, authoritatively handed down from the past. Intellectual progress was largely thought to depend on rediscovery and absorption of the achievements of ancient Greek and Roman civilizations. By 1800, Christianity had splintered. Many more alternative values and world-views had become known. And the cutting edge of intellectual progress was associated with the application of mathematical models and experimental methods to all aspects of nature.

The promise and threat of the changes in science was associated with the increasingly accepted idea of methodical doubt about all that earlier had been taken for granted. This led to questioning, discarding, and rejecting aspects of the past to start from scratch, abandoning authorities and preconceived ideas, encouraging attitudes that by the eighteenth century expanded to include new ideas for changing society.

.

Historical preconditions and influences that set the stage for the scientific revolution were many and varied:

- Broadening informational, geographical, and cultural horizons were brought about by:
  - The series of Crusades between the eleventh and fifteenth centuries.
  - Overland trade with Asia during the era of the Mongol Empires in the thirteenth and fourteenth centuries.
  - The voyages of discovery followed by colonization starting in the late fifteenth century gave not only individuals but governments a stake in gathering new information, which often cast doubt on traditional authorities.
  - A consistent trickle and occasional flood of philosophical, scientific, mathematical, and other works translated from Greek, Arabic, and Hebrew into Latin, starting in the twelfth century, and into vernacular languages from the seventeenth century; the publication in print of early Muslim as well as Greek and Hebrew scholarship.
  - Increasing demand for literacy and number skills in commerce and in government bureaucracies; acquaintance with scientific principles in crafts and industries such as metallurgy, mining, navigation, the making of scientific instruments.
  - New methods and institutions that promoted sharing of knowledge by different groups of people, such as universities, printing firms, scientific societies, salons, coffee-houses, reading groups, and public lectures.
  - The willingness of early modern scientists to draw on the experience and know-how of others, not only scientists and philosophers but also engineers, artisans, navigators, cartographers, gunners, and others.
- Increasing secularization of interests and power-bases increased focus on this world rather than on the afterlife; reduced the ability of religious authorities to stifle new scientific ideas that ran afoul of the Bible or church doctrines.
  - During the Middle Ages, education passed from cathedrals and monasteries to universities. Subjects belonging to natural philosophy became part of the formal university curriculum; theology, while still "queen of sciences," was only one professional school alongside medicine and law. Moreover, universities were self-governing corporations with a wide range of rights and privileges, including that of the faculty to decide what is to be taught.
  - Mobility of labor (partly due to scarcity caused by the Black Death), urbanization, and the use of mercenary armies, reduced the effectiveness of formal excommunication from the Church as a way to control belief and behavior.
  - Secular rulers appropriated powers previously held by Church authorities, such as appointing bishops, trying cases in secular rather than church courts; German princes and other rulers renouncing the Pope and joining the Protestant movement; Henry VIII making himself head of the Church of England.
  - During the Renaissance, a number of trends contributed to religion's loss of priority among a segment of the population: educated elites' admiration for classical authors, forms, and works; their emphasis on secular subject-matter, human-centered themes, and realistic representation of the human body; their critical approach to history that eventually spread to examination of religion-related writings.

    - The discovery and translation of many more works by Plato and his followers than had been known in the Middle Ages; the emphasis in these works on thinking about the world in mathematical ways made a big impact on the scholarly world.
    - From the sixteenth century, rulers and governments came to support science and scientists for the latter's pragmatic usefulness in many fields, such as navigation, metallurgy, and gunnery.
- Christianity's ability to give space within the faith's parameters for the pursuit of science, and the fact that its practitioners were faithful believers, helped give cultural legitimacy to the new science in the still devout seventeenth century.
    - Medieval scholastics, trying to reconcile Christianity with the philosophies of pagan Greece and Rome as well as with some Muslim writers, came to the conclusion that there was no inherently necessary conflict between science and faith.
    - The belief that God wrote two books, the Bible, and the "Book of Nature," by which his existence and intentions could be known. This idea was emphasized during the early modern period. Therefore, the study of nature had religious value, and the notion that humans should use their God-given faculties of observation and reason to read the "Book of Nature" accurately could be regarded as a religious duty.

Nevertheless, problems arose in specific instances where new ideas conflicted with the authority of Scripture, doctrine, or those ancient philosophers accepted as important for the faithful to study. Threats to these authorities were countered by religious institutions, though not always immediately, consistently, or successfully.

The widespread current of skepticism that developed in the sixteenth and seventeenth centuries encouraged questioning of authorities, beliefs, and previously held ideas. Contributing to the development of this skepticism were the shocks to established world-views, shaking of previously secure beliefs, disappointments with existing knowledge and authorities, and radical uncertainties created by the following:

- Early events that encouraged questioning traditional wisdom and institutions included the fourteenth-century Black Death, to which traditional society's response was wholly inadequate; the Popes' loss of authority to kings and to church Councils; and the scandal of two Popes, one in Rome and one in Avignon, France, claiming legitimacy.
- The success of the Protestant Reformation led to a splintering of Christendom into multiple denominations within European Christianity, all claiming to be the one true way to salvation.
- Devastating religious wars that involved most of Europe raged during virtually the entire period between the mid-sixteenth and mid-seventeenth centuries.

- Information was brought back from voyages of discovery and colonizing ventures about peoples who had radically different ways of thinking, behaving, and organizing society.

It would be easy to claim, and with justification, that the scientific revolution was a watershed event in history. Such a claim, however, does not do justice to the complexity of the phenomena for which "scientific revolution" is at best a shorthand term. This unit is intended to illustrate some of the complexities, to help students consider some of the questions raised, and to encourage them to raise some of their own.

This unit in the Big Era Timeline

Big Era Six 1400-1800 CE

The Scientific Revolution
1500-1800

Prelude to the Lessons
What is Science?

Introduction

You might want to share with students the information that:

- Before the nineteenth century, what we call science was referred to as natural philosophy, and was to varying degrees entangled with moral philosophy, theology, numerology, and magic.
- In the Middle Ages, the word “science” was used to mean ”knowledge” in a generic sense.
- By the Renaissance, science was often to also mean “art” in describing a particular body of knowledge. These usages continued until the early nineteenth century. But also, by the end of the sixteenth century, “science,” requiring theoretical knowledge, was often differentiated from “art,” a skill that required only practice.
- In the early eighteenth century, one author stated that the “the word ‘science’ is usually applied to a whole body of regular or methodical observations or propositions” about any subject.
- By 1800, though science mostly meant just the theoretical and methodical study of nature, it had for a growing number become associated with specific ways of thought and methods that we would now consider scientific.
- In the mid-nineteenth century, the word “scientist” was first used to replace the earlier term “natural philosopher;” and “science” referred primarily to the, by then, well-differentiated fields of physics, chemistry, and biology.
- The term “scientific revolution” was first given currency in 1939. Historians continue to disagree about whether the changes in science centering on the seventeenth century can appropriately be called a “revolution.”

Activities

1. Ask students to brainstorm, and/or discuss in groups or with a neighbor the following ideas. Share/summarize results with the whole class:

> A. If you had to give as good an explanation as you can in about five minutes of what science is to an interested fourth-grader, what would you say? [Ask each student to make a note of the main points of their own explanation. They will need to refer to it for Activity 12 in Lesson 3.]
>
> B. What kinds of things would it make you think of if you heard someone say “Oh, but that isn’t science,” “What an unscientific view. . . ,” “Science has established. . . ,” or “That was the scientific way to approach it”? Do the reactions in each case have anything in common? If so, what? If not, how would you account for the wide variation?

C. What characteristics distinguish science from what is not science? What distinguishes the scientific from what is not scientific? [It may help students to suggest that they consider, among other things,

- subject matter
- theories and hypotheses
- descriptions
- methods of observation and/or investigation.

2. Ask students in groups to formulate a hypothesis of what the 3-5 most important defining characteristics of science are, and to explain why they consider these to be the most important. Consider what kind(s) of information would

- strengthen their hypothesis
- weaken their hypothesis
- disprove their hypothesis
- suggest their hypothesis needed revision.

Have the groups share their hypotheses with the class, and encourage students to reach consensus on a single hypothesis, which should be recorded by everyone. It will be used again in Lessons 1 and 2.

3. Textbooks, scholars, and others routinely refer to a "scientific revolution" centered in Europe in the seventeenth century. Not all scholars, however, agree on whether use of the term "scientific revolution" is appropriate. What would have to have happened to make using the term "revolution" appropriate? What questions would you ask, the answers to which would help you decide more reliably whether the term is appropriate for what happened to science in seventeenth century Europe?

4. What historical conditions or events do you think would promote or hinder the development and spread of science? Scientific change? How? (It may help students to suggest that they consider political, social, economic, religious, technological, intellectual conditions and/or events.)

Lesson 1
Was There Science Before the Scientific Revolution?

Introduction

Note: Built into this unit are various opportunities for students to engage in some of the activities characteristic of what scientists did during the lead-up to and development of early modern science: reasoning; identification and evaluation of evidence; formulation, testing and refining of hypotheses; classification; using data to make generalizations and assess reliability; grappling with issues of truth and certainty, and maintaining a skeptical stance. Activity 11 in Lesson 3 gauges students' recognition of scientific characteristics in their work during the unit. Whether to share this feature of the unit with students right at the start and how far to take advantage of its possibilities will depend on individual circumstances.

The following suggested activities/discussions are based on students having read the documents in Lesson 1, the Student Handout.

Before reading the handout, students should know the following information:

- The documents in the Student Handout span a period from the tenth to the fourteenth centuries. They represent authors from different backgrounds in the Islamic and European worlds of the time, whose knowledge and mindset also varied by time and place.
- However, these scholars shared the bases for their knowledge of the universe: reliance on their religions' revealed truths, and on the works of Greek, Indian, Persian, and other thinkers most of whom lived before both the Prophet Muhammad and Jesus Christ. Dealing with the resulting contradictions between religious and classical authorities on the one hand, and truths based on revelation and reason on the other, created ongoing problems for Muslim and Christian scholars alike.
- The following beliefs about the structure and behavior of the universe drawn from Greek and Arabic sources were shared in their broad outlines throughout Europe and the Muslim world. What neither shared was our own clear differentiation of "science" from philosophy, religious ideas, logic, and common sense.
    - A motionless earth was the center of the universe. It was surrounded by water, beyond which was an envelope of air, in turn ringed by fire. This realm was imperfect and changeable. In it, the four elements of earth, water, air, and fire existed everywhere as varied mixtures, with heavy earth and water constantly striving downwards and light air and fire striving to rise. The whole was enclosed, and air as well as fire stopped from escaping upwards, by a set of nested, concentric, transparent heavenly spheres of crystal, the edge of each touching the edge of the next. (Imagine thick and regularly spherical skins a bit like those of an onion, but more transparent, around a central core.) The spheres moved around the earth, sliding against each other in a regular circular motion carrying with them the heavenly bodies, each embedded in one of them: the moon, five planets,

the sun (between Mars and Venus), and the fixed stars. Beyond these was the habitation of God and of saved souls.

- All the heavenly region was perfect, unchanging, and utterly different from the terrestrial region below the moon, where any movement was in a straight line, unlike the circular heavenly movements. But everywhere in the universe, in heaven as well as on earth, rest was characteristic of all bodies and objects. Unless moved by something, and unless the mover was in constant contact with the thing moved, no movement was possible.
- The explanation for movement of the spheres carrying heavenly bodies usually involved spiritual beings ("intelligences" or angels, the two words being used interchangeably) constantly turning each sphere. A ninth outer sphere, the Unmoved or Prime Mover, related to the other heavenly spheres the way the soul relates to the body: it provided the motive power transmitted to the rest of the spheres. On earth, the movement of falling bodies, for instance, was accounted for by the element of earth, which sought its natural home downwards, because of its heaviness. Flames, on the other hand, were light and rose upwards.
- The physical universe was hierarchical, as was the human. Lowest on the scale was the element earth. In ascending order, with less of earth and more of the lighter elements in their make-up, were beings with vegetative, animal, and rational (human) souls. From the moon's sphere upward, a hierarchy of angels, with spiritual souls, moved the heavenly spheres, with God above all. Each sphere was ruled the ones below it.
- Humans mirrored the physical universe, which deeply affected human affairs. Movements of heavenly bodies influenced what humans did and what happened to them. Parts of the body were "ruled" by planets and signs of the zodiac. Astrology, barely if at all distinguished from astronomy, was therefore enormously important in decision-making by rulers and commoners alike.

Activities

Ask students to respond to the following:

1. Describe the kinds of support for the statements made, and/or the kinds of evidence given, by the authors of the documents in the Lesson 1 Student Handout.

2. Identify the distinctive characteristics of medieval science, based on your reading of the documents. What would you consider its 3-t0-5 most distinctive characteristics? Why? Support your argument with evidence.

3. (This activity lends itself well to small group work.) Assume that you have just been chosen to serve on a panel charged with naming someone to appear on the cover of *Time Magazine* as "The Outstanding Medieval Scientist." If your only choices were the people represented by the documents in the Student Handout, and all you had to go on to judge the scientific quality of their work was the document in the handout, whom would you nominate? Justify your

nomination to *Time*'s editors by explaining your reasons for your choice. (Students may be reminded of Introductory Activities 1C, when they discussed what features distinguish science from non-science not science, and the scientific from what is not scientific.)

4. Which three documents would you recommend being included in a chapter on medieval science in a textbook? Justify your selection with reference to the documents and to what you know about the Middle Ages.

5. What did you find most surprising about the documents and the information in them? Explain.

6. What are the 2-to-3 most important things you have learned about medieval science by reading these eight documents? How did you decide which things were the most important?

7. Which of the 3-to-5 most important defining characteristics of science set out in the hypotheses created during the Introductory Activities can you identify in the documents? In which documents?

8. Do you need to change your hypothesis about what the important defining characteristics of science are? Why or why not? If yes, what would you change and why?

9. (This activity may serve as assessment. Drawing on the information in the documents, list all the evidence you can in favor of and opposed to the claim that "there was no such thing as science during the Middle Ages." Do you judge the claim to be accurate? Why or why not?

Extension

1. Review information from your textbook and/or notes about the history of Afroeurasia between about 900 and 1400.
    - What political, economic, social, and religious conditions are likely to have contributed to the characteristics of Islamic/European science during that period shown in this lesson? How?
    - For what information about the Middle Ages in your textbook can you find confirmation in the documents in the Student Handout?

2. Research information about the authors of the documents in this lesson.
    - Where were they from? What was their occupation? In what fields of knowledge did they work?
    - In what ways were they similar, in what ways different, from people working in science today?

Lesson 1

Student Handout—Was There Science Before the Scientific Revolution?

Document A. "The Shape of the Seas" from Al-Mas'udi's tenth-century work on geography

The philosophers differ about the shape of the seas. Most of the ancients, such as the mathematicians of the Hindus and the Greeks, believe that they are round. They provide many arguments as proofs of their statement. [For instance,] if you sail away on the sea, land and mountains disappear gradually, until you lose sight of even the highest mountain peaks. On the other hand, as you near the coast, you first see the mountains. Only when you come nearer do you see the trees and plains.

But those who strictly follow the revelation [the Qur'an], reject this hypothesis.

Source: Qtd. in Seyyed Hossein Nasr, *Science and Civilization in Islam* (Cambridge: Harvard UP, 1968), 107. Language simplified by Anne Chapman.

Document B. "Lead into Gold?" from ibn Sina's (Avicenna's) eleventh-century *Book of the Healing*

As to the claims of the alchemists [that they can turn one metal into another, and particularly into silver or gold], it must be clearly understood that it is not in their power to bring about any true change of species. [Ibn Sina considered that each metal was a distinct species of the genus "metals." Just as it was impossible to turn a horse into a dog, so it was impossible to turn one metal into another.]

They can, however, produce excellent imitations, dyeing the red [metal] white so that it closely resembles silver, or dyeing it yellow so it closely resembles gold. . . . Yet in these [dyed metals] the essential nature remains unchanged; they are merely so dominated by induced qualities that errors may be made concerning them.

I do not deny that such a degree of accuracy may be reached as to deceive even the shrewdest, but [as for] the possibility of eliminating or imparting the [difference in species], I regard it as impossible. . . . Those properties which are perceived by the sense are probably not the differences which separate the metals into species, but rather accidents or consequences, the [actual] differences being unknown. And if a thing is unknown, how is it possible for anyone to endeavor to produce it or to destroy it?

Source: E. J. Holmyard and D. C. Mandeville, eds. and trans., *Avicennae "De congelatione et conglutinatione lapidum" Being Sections of the "Kitab al-Shifa"* (Paris: Librairie Orientaliste Paul Geuthner, 1927), 17-32. Quoted in Edward Grant, ed. *A Source Book in Medieval Science* (Cambridge: Harvard UP, 1974), 572.

Document C. "Answers to Questions About Nature" from Adelard of Bath's twelfth-century natural history

I have learnt one thing from my Arab masters, with reason as guide, but you another: you follow the halter of authority. As brute animals are led by a halter, but do not know where or why they are led, so the authority of written words leads not a few of you into danger, since you are held captive by brutish blind faith. These days listeners do not demand arguments based on judgment. They do not understand that reason has been given to each single individual in order to decide between true and false with reason as the prime judge. However, I do not unconditionally state that authority should be rejected. Rather, reason should be sought first, and an authority, if one is at hand, be added later. Authority alone cannot win credibility for a philosopher. . . . If you wish to hear anything more from me, give and receive reason. . . .

Question: Why is seawater bitter and salty?

Answer: The heat of the sun and the planets causes the saltiness. Since the true Ocean flows through the hot central zone of the earth, and the planets move through the same zone, so because of the great heat of the stars [Adelard uses "planet" and "star" interchangeably] the sea itself becomes hot. As a result it becomes salty. This is confirmed by the fact that on seashores near that Ocean seawater dried on the rocks becomes salt without any artifice. To get salt from seas further away, distant from heat, the seawater must be heated again by boiling. But even some fresh water can be turned into salt if it is boiled down. Moreover, in summer all seawater is saltier than in the winter, which anyone can experience for themselves. . . .

Question: Are stars animate or inanimate?

Answer: Whoever thinks they are inanimate is himself without a soul in my opinion. If this [earthly] region which is churned about with hail, bristling with clouds, and murky with darkness can sustain reason and judgment, how much more is the ethereal plane [the Heavens, which is] purged of all uncleanness, obedient to mind and reason?

Again, if of all created things nothing can be better than the mind, should the place [the perfect Heavens] which is most suitable for it be deprived of it? As for stars' form, it is clear that the form of the stars, which is full and round [the circle being considered the most perfect shape] is of all forms the most appropriate to the soul. . . .

Nothing, then, among creatures is more rational than [stars].

Source: Charles Burnett, ed. and trans., *Adelard of Bath: Conversations With His Nephew* (Cambridge: Cambridge UP, 1998), 103-4,185-6, 219-22. Language simplified by Anne Chapman.

Document D. "Accuracy of Measurement" from Abu'l-Fath al-Khazini's twelfth-century book on mechanics

[The main principle al-Khazini used in determining specific gravities was that a given body will float in a liquid to a depth proportional to the specific gravity of the liquid, sinking further in a light than a dense one. Great care was taken to ensure the maximum possible accuracy in the design, manufacture, and calibration of his measuring instrument, based on that of the Greek mathematician and scholar of mechanics, Pappus.]

Substances	al-Khazini's 1121 values for their specific gravity	Twentieth-century values
Water	1.00	1.00
Sea water	1.04	1.029--1.04
Olive oil	0.92	0.918—0.919
Cow's milk	1.11	1.02—1.04
Mercury	13.56	13.56
Brass	8.57	8.45—8.60
Tin	7.32	7.29
Iron	7.74	7.60—7.79

Source: Qtd. in Donald R Hill, *Islamic Science and Engineering* (Edinburgh: Edinburgh UP, 1993), 66.

Document E: "The Ecstatic Camel" from al-Mustaufi al-Qazwini's thirteenth-century encyclopedia

The Eternal Wisdom designed animals to be of use to man, the perfected of perfections. Since He created them as tools for man, God (may He be praised and exalted!) directed man so he got the upper hand of them. . . .

Of domestic animals, I shall list ten kinds in alphabetical order. . . .

The camel is a large-bodied, strangely made animal that eats little, bears burdens, and is obedient to commands. It is liable to ecstasy and gladness. Shaikh Sa'di [Persian poet and traveler] says: "The camel becomes ecstatic and dances at the Arab's song; if you are not joyful, you are a cross-grained beast."

All the sects are allowed to eat its flesh, which is warm and dry. The camel is intelligent, so when it is sick it eats oak-leaves and gets better, and when a poisonous snake bites it, it eats a crab and the poison is neutralized.

Its liver gives clear sight and prevents cataracts. Snakes flee from wherever its fat is put down. Tying its hair around the left thigh halts diabetes.

The Arabs call a male camel *jamal*, the female *naqat*, the young *bakr*, the old *nab*, a baggage carrier *hamulet*, a milk camel *laquh*, a 3-year old *hiqq*, a 4-year old *jadha*. . . .

Source: Qtd. in Seyyed Hossein Nasr, *Science and Civilization in Islam* (Cambridge:: Harvard UP, 1968), 119-20. Language simplified by Anne Chapman.

Document F. "Description of the Magnet" from Bartholomew the Englishman's thirteenth-century account

The magnet is an Indian stone that attracts iron, as Isidore [Spanish bishop and encyclopedist] says. It is also believed to attract clear glass. As Augustine [African bishop, theologian, and philosopher] says, its force is so great that iron will follow its movement even through a shield of gold or bronze. Due to this power of a magnet, a statue made of iron was seen to hang in the air in a temple.

There is another species of magnet in Ethiopia which repels iron and flees from itself. Also, the magnet sometimes attracts iron from one angle, and repels it from another. Isidore adds that this kind of stone restores husbands to wives and increases elegance and charm in speech.

There are mountains made of such stones that attract and dissolve ships made of iron. Its dust is especially valuable for wounds and against dropsy, spleen, and fox mange, as Avicenna [ibn Sina, Muslim physician, scientist and philosopher] says.

Source: Anglici Bartholomaei, *De genuinis rerum coelestium terrestrium et inferarum proprietatibus libri XVIII* Edward,Grant, trans. (Frankfurt: Minerva, 1964). Qtd. in Edward Grant, ed. *A Source Book In Medieval Science* (Cambridge: Harvard UP, 1974), 367-8. Language adapted by Anne Chapman.

Document G. "The Nature of Comets" from Albertus Magnus' thirteenth-century treatise

We will give the correct view about comets, and confirm it by the authority of many physicists. I say, then, that a comet is nothing else than a coarse earthly vapor or fumes; coarse, because if it were thin it would quickly evaporate and dissolve. It gradually rises from the bottom of the layer of air to the top, where it touches the curved inner surface of the sphere of fire. There it is thinned out by the heat of the fire and inflamed. Its middle always stays dense, but what is thinned out at the sides often seems long, has a thin flame, and is called the "tail."

The famous philosophers Avicenna [ibn Sina, Muslim physician, scientist and philosopher] and Algazel [al-Ghazali, Arab theologian and philosopher] give evidence that this is so. Ptolemy [Greek astronomer and geographer] and Albumasar [Abu Ma'shar, Persian astronomer and mathematician] also imply this.

Reason, too, supports this opinion. Since it is evident that flame is nothing but kindled fumes; and a comet is a sort of flame, as is apparent to the sight, therefore, a comet is kindled fumes.

Furthermore, if a comet is always produced by one of the five planets as some have argued, then it should never be seen outside the path of the planets. Yet this is false, since Aristotle [Greek philosopher and scientist] says we see comets in every part of the sky. Moreover, I with many others in Saxony in the year 1240 saw a comet close to the North Pole. It projected its rays between east and south, and it is evident that there was not the path of any planet.

Source: Lynn Thorndike, ed. *Latin Treatises On Comets Between 1238 and 1368 AD* (Chicago: University of Chicago Press, 1950), 499-508. Qtd. in Edward Grant, ed. *A Source Book In Medieval Science.* Cambridge: Harvard UP, 1974), 543-4.

Document H. "A New Theory of Motion" from Jean Buridan's fourteenth-century "Questions On Aristotle"

The question is what moves a thing that has been thrown after it has left the hand of the thrower. Is it moved by air, or if not, by what is it moved?

Aristotle has not solved this problem well. He suggests that the thing thrown leaves the place where it was quickly, and would leave emptiness behind. But nature, which does not allow a vacuum, quickly sends air in behind to fill up emptiness. The air that has moved in fast this way, comes up against the end of the thing thrown, and pushes it along further. This is repeated continually. But it seems to me this explanation is without value because of many experiences that contradict it.

For instance, a lance having a pointed back end as sharp as the front would be moved, after having been thrown, just as fast as it would be with a blunt back end. But surely the air following would push a pointed end less well, because the air would be easily divided by the sharpness.

Again, a ship pulled along fast in the river even against the current cannot be stopped quickly, but rather continues to move for a long time after the pulling stops. And yet a sailor on deck does not feel any air from behind pushing him. On the contrary, he feels the air from the front resisting him.

Instead, we can and should say that the mover in moving anything impresses in that thing a certain impetus or motive force, which acts in the direction that the mover was moving the thing. The faster the mover moves the thing, the stronger the impetus he impresses in it. This theory explains why the motion of a heavy body downwards is continually accelerated. At the beginning, only gravity was moving it; but moving impressed in it an impetus, which, added to the gravity, made the movement faster, in turn making the impetus stronger and so on.

Also, the Bible does not state that each heavenly body is moved by an intelligence [or angel—the two words were used interchangeably.]. So it could be said that it does not appear necessary to hypothesize intelligences of this kind to account for the movement of planets and fixed stars, as many do. It could instead be said that God, when he created the world, moved each heavenly body as He pleased, and in doing so impressed in them impetuses that moved them without him, or anything else, having to move them any longer. But this I do not say assertively, only tentatively, so that I might seek from the theological masters that they teach me in these matters.

Source: Qtd. in Marshall Clagett, *The Science of Mechanics In the Middle Ages* (Madison: University of Wisconsin Press, 1957), 532-6. Language adapted by Anne Chapman.

Lesson 2
Science Comes of Age: Was It a Revolution?

Introduction

The following suggested activities/discussions are all based on students having read the documents in the Lesson 2 Student Handout.

Before reading handout, students should know that the documents span a period from the sixteenth to the eighteenth centuries, and they represent authors from different European backgrounds whose knowledge and attitudes also varied by time and place**.**

The shared knowledge of the Middle Ages continued on in those centuries, though with gradual changes. It was buttressed by religion, which resisted any change that ran afoul of holy scripture or doctrines. It was also supported by the slow rate of change in the universities.

Activities

Ask students to respond to the following:

1. Describe the kinds of evidence given by the authors of the documents, and/or how they support the statements they make.

2. Pick the three documents in the Lesson 1 Student Handout that you consider most unlike any of the documents in the Lesson 2 Student Handout. Compare them to the three documents in the Lesson 2 Student Handout that come closest to resembling them. Identify both similarities and differences. Then pick the three documents in the Lesson 2 Student Handout that you consider most unlike any of the documents in the Lesson 1 Student Handout. Compare them to the three documents in the Lesson 1 Student Handout that come closest to resembling them. Identify both differences and similarities.

- How important were the similarities? The differences? Explain on what basis you judged importance.
- Based on your comparisons, what generalizations can you make about similarities and differences between medieval and early modern science? On what grounds could the generalizations you make be questioned? Defended? What questions could you ask whose answers might help improve the reliability of your generalizations?
- What conclusions can you draw from this exercise about science during the period covered by the two student handouts? Explain how you arrived at your conclusions.

3. Identify the distinctive characteristics of sixteenth-eighteenth century science, based on your reading of the documents. What would you consider the 3-to-5 most distinctive characteristics of science during this period? Why do you consider these the most distinctive? Support your argument with evidence.

4. On what basis would you question, on what basis defend, the reliability of the selection of documents in the Lesson 2 Student Handout for making generalizations about what early modern science was really like?

5. What questions would you ask whose answers would increase your confidence that the documents in the Student Handout can reliably be used as the basis for generalizations about what early modern science was really like? If you could go beyond the documents supplied in the Student Handout, what could you do to increase the reliability of any generalizations you made about what early modern science was really like? What difference would it make if you tried to do this as a student, or as a scientist?

6. (This activity is best done in groups.) Before they begin, students may be reminded of Introductory Activity 1C, when they discussed what characteristics distinguish science from what is not science, and the scientific from what is not scientific. Assume that you are members of a panel charged with nominating a winner, and a runner up, for the honor of being named the "Scientist Whose Work Most Closely Represents the Ideals of Modern Science" title. Your only candidates are the authors of the documents in the Student Handout. And all you know about them is what is in those documents. Which two or three of them would you eliminate first, and whom would you nominate as winner and as runner up? Justify your choices.

If you could nominate anyone from the 1500-1800 period, would you stay with your original nominee for winner, or choose someone else? If you would choose someone else, who would that be? In what ways is your alternative selection more representative of the ideals of modern science than your original one? (Students could be asked to do research to find out more about their original choice and their suggested alternative, so they would be better able to answer the last question.)

7. Based on the documents in the Lessons 1 and 2 Student Handouts, and on what you know about modern science, what evidence could you give for, and against, the claim that some basic features of later scientific thinking were already present in the Middle Ages?

8. What pre-scientific or non-scientific ways of thought that carried over into the sixteenth-eighteenth centuries can you identify in the documents in the Lesson 2Student Handout? Which documents? Explain why you consider them pre-scientific or non-scientific.

9. Drawing on information in Lessons 1 and 2, identify changes and continuities in science during the tenth through eighteenth centuries (and/or during the sixteenth through eighteenth centuries). Were the changes or the continuities more important? Explain.

10. You have been named as a consultant to a publisher and asked to work on the chapter about the scientific revolution in the textbook they are about to bring out. Which five documents, drawn from either Lesson 1 or Lesson 2, would you recommend should be included in a chapter on the scientific revolution in their textbook? Justify your selection to the editors, referring to the

documents and to what you know about the historical periods during which the documents were written.

11. This activity may serve as assessment. It could be restricted to only the Lesson 2 Student Handout and to change between 1500 and 1800. Based on your reading of the documents in the Lessons 1 and 2 Student Handouts, explain the ways in which science changed between the Middle Ages and the eighteenth century. Support your arguments with evidence.

12. This activity may serve as assessment. Drawing on the information in the documents, list all the evidence you can in favor of, and opposed to, the claim that "there was no such thing as a scientific revolution." Do you judge the claim to be accurate? Why or why not?

13. This activity could serve as assessment.) You have been invited to give a talk in a history class to students about two years younger than yourself. Your topic is "The scientific revolution." Basing your talk on the information in Lessons 1 and 2:

- What would be the half dozen or so most important points you feel would help your audience understand what is meant by the "scientific revolution"? What additional points might you want to make?
- What is the indispensable information you would have to give them so they will understand how the scientific revolution came to be? What additional information might you want to add?
- Explain how you decided on what was "most important," and on what was "indispensable."

14. Which of the 3-to-5 most important defining characteristics of science set out in the hypotheses created during the Introductory Activities can you identify in the documents? In which documents?

15. Do you need to change your hypothesis about what the significant defining characteristics of science are? Why or why not? If yes, what would you change and why?

Extension

1. According to Leonardo da Vinci (Lesson 2 Student Handout 2), "Where there are quarrels there true science is not; because truth can only end one way—wherever it is known, controversy is silenced for all time, and should controversy nevertheless arise again, then our conclusions must have been uncertain and confused. . . ."

This quote suggests that he considered that lack of disagreement could be accepted as a reliable test of certain truth. Do you share his view? Why or why not? Judging by the other documents in the Student Handout, how many of their authors shared Leonardo's view? What other tests of truth can you identify in the other documents of the Student Handout? Which of them would you yourself accept as most reliable? Why? What other reliable tests of truth could you suggest?

Lesson 2

Student Handout—Science Comes of Age: Was It a Revolution?

Document I. "Minds and Hands Both Needed" from Leonardo da Vinci's 1510's manuscript on painting

They say knowledge born of experience is mechanical, but that knowledge born and consummated in the mind is scientific. . . . But to me it seems that all sciences are vain and full of errors that are not born of experience, mother of all certainty, and that are not tested by experience, that is to say that do not . . . pass through any of the five senses.

For if we are doubtful about the certainty of things that pass through the senses, how much more should we question the many things against which these senses rebel, such as the nature of God and the soul and the like, about which there are endless disputes and controversies. . . . Where there are quarrels there true science is not; because truth can only end one way—wherever it is known, controversy is silenced for all time, and should controversy nevertheless arise again, then our conclusions must have been uncertain and confused. . . .

Experience . . . always proceeds from accurately determined first principles, step by step in true sequences . . . as can be seen in the elements of mathematics founded on numbers and measures called arithmetic and geometry, which deal with discontinuous and continuous quantities with absolute truth. Here no one argues as to whether twice three is more or less than six. . . .

Astronomy and the other sciences also entail manual operations although they have their beginning in the mind, like painting, which arises in the mind of the contemplator but cannot be accomplished without manual operation. The scientific and true principles of painting first determine what is…darkness, light, color, body, figure, position, distance, nearness, motion, and rest. These are understood by the mind alone and entail no manual operation; and they constitute the science of painting which remains in the mind . . . and from it is then born the actual creation [which needs hands].

Source: Qtd. in Elizabeth G. Holt, ed., *A Documentary History of Art*, vol. 1 (Garden City, NY: Doubleday Anchor, 1957-), 275-7.

Document J. "The Earth Moves" from Copernicus's 1543 book *On the Revolutions of Heavenly Orbs*

When I had thought for a long time about the uncertainty of the traditional mathematical doctrine concerning the paths of the heavenly bodies, it seemed to me very regrettable that no more correct theory had yet been advanced by philosophers for the movements in that universe which the best and most perfect Architect had made for us. . . .

Therefore I took the pains to read through the writings of all the philosophers that I could get together in order to find out if some one of them had not stated the opinion that the movements of the heavenly bodies might be other than the professional mathematicians had claimed. And I did find . . . in Cicero [Roman lawyer, politician and philosopher] that Nicetas [Byzantine bishop and writer on religious topics] had thought that the earth moves. I read in Plutarch [Greek biographer and historian] that some others also had been of this opinion. . . .

When I had received this suggestion I began myself also to meditate upon a motion of the earth. And although this theory might seem nonsensical, yet because I knew that others before me were allowed the liberty to suppose all sorts of circles in order to explain the phenomena in the heavens, so I too would be permitted to try whether building on the theory of the earth's motion I might find more satisfactory explanations for the movements of the heavenly bodies.

After I had then assumed the motions which I assign to the earth in the following work, I found, after careful investigation extending through years, that if the movements of the other planets were referred to the motion of the earth in its orbit and reckoned according to the revolution of each star, not only could their observed phenomena be logically explained, but also the succession of the stars, and their size, and all their orbits, and the heavens themselves would present such a harmonious order that no single part could be changed without disarranging the others and the whole universe. In accordance with this theory I have drawn up the plan of my work. . . .

The first thing for us to realize is that the universe is spherical. This is so either because, of all forms, the sphere is most perfect, requiring no joins; or because it is the most capacious, and so best fitted to enclose and preserve all things; or because all things strive to be bounded thus, as we observe in drops of water and other liquids. There can be no doubt, then, about the rightness of assigning this shape to the heavenly bodies.

Source: Qtd. in H. Webster, *Historical Selections* (Boston: D. C. Heath, 1929), 885-6; and in Dennis Richard Danielson, *The Book of the Cosmsos* (Cambridge, MA: Perseus, 2000), 108. Language simplified by Anne Chapman.

Document K. "About Magnets" from William Gilbert's 1600 book *On the Great Magnet the Earth*

For the discovery of secret things and the investigation of hidden causes, sure experiments and demonstrated arguments are preferable to probable conjectures and the opinions of philosophical speculators. Aiming for the better understanding of that great loadstone [magnet] the earth, and of the extraordinary forces of this globe, we have decided to begin first with magnetic bodies and the parts of the earth that we may handle and perceive with the senses, and then to proceed with magnetic experiments… Every day, in our experiments, novel, unheard-of properties came to light. . . .

Many things in our reasonings and our hypotheses will perhaps seem hard to accept, since they differ from the general opinion. But I have no doubt that hereafter they will win authoritativeness from the demonstrations themselves. . . .

We do not at all quote the ancients and the Greeks as our supporters. Our doctrine of the loadstone contradicts most of the principles and theories of the Greeks. . . . We have had no hesitation in setting forth, in hypotheses that are provable, the things that we have through a long experience discovered.

Wood floating on water never turns by its own forces towards the poles of the world save by chance. Neither do threads of gold, silver, copper, zinc, lead, nor glass, when passed through cork and floated, ever have sure direction. When rubbed with a loadstone they show neither poles nor points of variation; for bodies that do not of their own accord turn towards the poles and are not obedient to the earth are in no way governed by the loadstone's touch. The energy of the loadstone cannot enter them, nor, if it could enter them, would that energy have any effect. This because the [magnetic] property of the earth is debased in them because it is mixed with a variety of other humors… The properties of iron, on the other hand, are awakened by the approach of a loadstone, and put forth their strength. . . .

Here we must express wonder at the false opinion of Baptista Porta, [author of *Natural Magic*, 1558, which includes discussions of magnets, experiments, cookery, alchemy, and demonology] who claims that iron rubbed with a diamond turns to the north. Now this is contrary to our magnetic rules; and therefore we made the experiment ourselves with seventy-five diamonds in the presence of many witnesses, using a number of iron bars and pieces of wire, manipulating them with the greatest care while they floated in water, supported by corks; yet never did I see the effect mentioned by Porta. . . .

Source: William Gilbert, *On the Loadstone and Magnetic Bodies, and On the Great Magnet the Earth.* Trans. P. Fleury Mottelay (New York: John Wiley and Sons, 1893), xlvii-li, 217-8. Language simplified by Anne Chapman.

Document L. Acceptance of Proven Truth from Cardinal Bellarmine's 1616 letter to a defender of Copernicus's theory

If there were a real proof that the Sun is in the center of the universe, that the Earth is in the third heaven [the third from the center of the eight or nine crystalline spheres or "heavens" into which the planets and stars were thought to be fixed] and that the Sun does not go round the Earth but the Earth round the Sun, then we should have to proceed with great circumspection [care] in explaining passages of Scripture which appear to teach the contrary, and rather admit that we did not understand them than declare an opinion to be false which is proved to be true.

But, as for myself, I shall not believe that there are such proofs until they are shown to me. Nor is it proof that, if the Sun [was] supported at the center of the universe and the Earth in the third heaven, everything works out the same as if it were the other way around. In case of doubt we ought not to abandon the interpretation of the sacred text [Bible] as given by the holy Fathers.

Source: Quoted in Peter Dear, ed., *The Scientific Enterprise in Early Modern Europe: Readings from Isis* (Chicago: University of Chicago Press, 1997), 147-8.

Document M. "Insect Experiments" from Francisco Redi's 1668 book on the *Generation of Insects*

It is not only the popular belief, but it is also stated authoritatively by both ancients and moderns that the rotting of a dead body, or any sort of decayed matter, can give being to worms just by itself. Desiring to trace the truth of the case, I made the following experiment.

I ordered three snakes to be killed . . . [and] placed them in an open box to decay. Not long afterwards I saw that they were covered with worms . . . .intent on devouring the meat. . . . When the meat was all consumed, the worms eagerly sought an exit, but I had closed every opening. Nineteen days later, some of the worms ceased all movements . . . and appeared to shrink and gradually assume a shape like an egg. . . . I placed these . . . . separately in glass vessels, well covered with paper, and at the end of eight days . . . from each came forth a fly. . . .

I continued similar experiments with the raw and cooked flesh of the ox, deer, buffalo, lion, tiger, dog, lamb, kid, rabbit; and sometimes with the flesh of ducks, geese, hens, swallows, etc. Finally I experimented with different kinds of fish. . . . In every case, flies were hatched. Almost always, I saw that the decaying flesh and the cracks in the boxes where it lay were covered not alone with worms, but with the eggs from which, as I have said, the worms were hatched. . . .

Having considered these things, I began to believe that all worms originated from the droppings of flies, and not from the decay of the meat. I was still more confirmed in this belief by having found that, before the meat grew wormy, flies had hovered over it, of the same kind that later bred in it.

Belief would be vain without the confirmation of experiment.

Therefore, I put a snake, some fish, some eels . . . and a slice of veal in four large, wide-mouthed flasks. Having well closed and sealed them, I then filled the same number of flasks in the same way, only leaving these open. It was not long before the meat and the fish, in these second vessels, became wormy and flies were seen entering and leaving at will.

Outside the closed flasks, on the paper cover, there was now and then a deposit, or a maggot that eagerly sought some crack through which to enter and feed. But in them I did not see a worm. Meanwhile, the different things inside the flasks had become putrid and stinking. . . .

I thought I had proved that the flesh of dead animals could not generate worms unless the eggs of live ones were deposited therein.

Source: Francesco Redi, *Experiments on the Generation of Insects*. Trans. M. Bigelow (Chicago: Open Court Publishing, 1909), 22-36. Text slightly rephrased for clarity by Anne Chapman.

Document N. "I Believe in Witchcraft" from Addison's 1711 essay in the periodical *The Spectator*

There are some opinions in which a man should stand neuter, without engaging his assent to one side or the other. Such a hovering faith as this, which refuses to settle upon any destination, is absolutely necessary in a mind that is careful to avoid errors and prepossessions. What the arguments press equally on both sides on matters that are indifferent to us, the safest method is to give ourselves up to neither. . . . I believe in general that there is, and has been such a thing as witchcraft; but at the same time can give no credit to any particular instance of it.

Source: Quoted in Phyllis J. Guskin, "The Context of Witchcraft," *Eighteenth Century Studies* 15 (1981): 58.

Document O. "Technology Adopts Science" from Leupold's 1725 treatise on improving machinery

His Majesty the King of Poland and His Highness the elector of Saxony have been graciously pleased to command me to supervise and to improve the organization of the engineering and machines of all the mines. . . . For [this], the following preparation is necessary:

1. A clear list must be made of all devices and machines which are in the mines or foundries . . . their parts and component pieces must be drawn accurately to scale . . . and calculated by Theory.

2. The power of each engine must be calculated as accurately as possible and . . . what [it] is now doing and what according to principles or theory it should be doing. . .

3. At the same time, all the mechanical and physical foundations and causes of both performance and non-performance should be explained clearly by experiments and sketches, together with the calculations, both geometrical and mechanical. . . .

5. I have invented devices for measuring . . . water-power, so that by means of an accurate clock with a second-hand . . . and of certain tables and rules, anyone should be able to calculate that in one minute or in one second, so much water will flow through. . . .

8. I will produce divers machines, inventing them entirely anew, in order to investigate the power of falling water [which is] . . . one of the most important items; for the whole question of improving machinery depends on (1) the right application of force, (2) the elimination of friction. . . .

9. I will give faithful guidance and teaching by experiments and on the engines at every mining-town or district where I find mining-crafts and persons who have need of the principles governing mechanics and their engines, and who are desirous of knowledge.

Source: Quoted in Friedrich Klemm, *A History of Western Technology,* trans. D. W. Singer (New York: Charles Scribner's Sons, 1959), 238-9.

Document P. "History As Science" from David Hume's 1748 book *Concerning Human Understanding*

It is universally acknowledged that there is great uniformity among the actions of men, in all nations and ages, and that human nature remains still the same. . . . The same motives always produce the same actions. The same events follow from the same causes. . . .

Mankind are so much the same in all times and places that history informs us of nothing new or strange. . . . Its chief use is only to discover the constant and universal principles of human nature, by showing men in all varieties of circumstances and situations, and furnishing us with materials from which we may form our own observations. . . . These records of wars, intrigues, factions, and revolutions are so many collections of experiments, by which the politician or moral philosopher fixes the principles of his science, in the same manner as the physician or natural philosopher becomes acquainted with the nature of plants, minerals, and other external objects, by the experiments which he forms concerning them.

Source: Quoted in Isaac Kramnick, *The Portable Enlightenment Reader* (New York: Penguin Books, 1995), 359-60.

Document R. "Science Leads to God" from Colin Maclaurin's 1775 book on Newton's Discoveries

A strong curiosity has prompted men in all times to study nature; every useful art has some connections with this science…But natural philosophy [science] is subservient to purposes of a higher kind, and is chiefly to be valued as it lays a sure foundation for natural religion and moral philosophy; by leading us, in a satisfactory manner, to the knowledge of the Author and Governor of the universe…

Source: Quoted in Carl L. Becker, *The Heavenly City of Eighteenth-Century Philosophers* (New Haven: Yale UP, 1932), 62.

Sir Isaac Newton (1643-1727)
English Physicist and Mathematician
Mezzotint by James McArdell after Enoch Seeman. 1760. Prints & Photographs Division, Library of Congress LC-USZ62-10191

Document S. "Dare to Know!" from Kant's 1784 essay on "What is Enlightenment?"

Enlightenment is man's emergence from his self-imposed nonage [immaturity.] Nonage is the inability to use one's own understanding without another's guidance. This nonage is self-imposed if its cause lies not in lack of understanding but in indecision and lack of courage to use one's own mind without another's guidance. *Sapere aude!* [Dare to know!] "Have the courage to use your own understanding," is therefore the motto of the Enlightenment.

Laziness and cowardice are the reasons why such a large part of mankind gladly remain minors all their lives, long after nature has freed them from external guidance. They are the reasons why it is so easy for others to set themselves up as guardians. It is so comfortable to be a minor. If I have a book that thinks for me, a pastor who acts as my conscience, a physician who prescribes my diet, and so on—then I have no need to exert myself. I have no need to think, if only I can pay; others will take care of that disagreeable business for me. Those guardians who have kindly taken supervision upon themselves see to it that the overwhelming majority of mankind—among them the entire fair sex—should consider the step to maturity not only as hard, but as extremely dangerous.

First, these guardians make their domestic cattle stupid and carefully prevent the docile creatures from taking a single step without the leading-strings to which they have fastened them. Then they show them the danger that would threaten them if they should try to walk by themselves. Now, this danger is really not very great; after stumbling a few times they would, at last, learn to walk. However, examples of such failures intimidate and generally discourage all further attempts. . . .

Enlightenment requires nothing but freedom—and the most innocent of all that may be called "freedom": freedom to make public use of one's reason in all matters. Now I hear the cry from all sides: "Do not argue!" The officer says: "Do not argue! Drill!" The tax collector: "Do not argue! Pay!" The pastor: "Do not argue! Believe!" Only one ruler in the world says: "Argue as much as you please, and about what you please, but obey!"

We find restrictions on freedom everywhere. But which restriction is harmful to enlightenment? I reply: the public use of one's reason must be free at all times, and this alone can bring enlightenment to mankind.

Source: Qtd. in Peter Gay, ed. *The Enlightenment: A Comprehensive Anthology* (New York: Simon and Schuster, 1973), 384-6.

Document T. "Science and Progress" from Condorcet's 1793 *The Progress of the Human Mind*

The progress of philosophy and the sciences has favored and extended the progress of letters, and this in turn has served to make the study of sciences easier. . . .

Scholarship . . . . already knew how to weigh up authorities and compare them; it now learned how to bring every authority before the bar of reason. . . . Nevertheless, we still see the forces of enlightenment in possession of no more than a very small portion of the globe, and the truly enlightened vastly outnumbered by the great mass of men who are still given over to ignorance and prejudice. . . .

The progress of the sciences ensures the progress of the art of education which in turn advances that of the sciences. This reciprocal influence . . . deserves to be seen as one of the most powerful and active causes working for the perfection of mankind. . . . As each [science] advances, the methods of expressing a large number of proofs in economical fashion and so making it easier to understand them, advance with it. . . .

In the political sciences there are some truths that, with free people . . . can be of use only if they are widely known and acknowledged. So the influence of these sciences upon the freedom and prosperity of nations must in some degree be measured by the number of truths that, as a result of elementary instruction, are common knowledge; the swelling progress of elementary instruction, connected with the necessary progress of these sciences, promises us an improvement in the destiny of the human race. . . .

Source: Quoted in Alfred J. Andrea and James H. Overfield, eds. *The Human Record: Sources of Global History*, Vol. 2 (Boston: Houghton Mifflin, 1990), 182-5.

Lesson 3
What Influenced Science, and How?

Introduction

The following suggested activities/discussions are all based on students having read the Lesson 3 Student Handout. Students could work on the activities as a whole class, or they can do them as individuals, in pairs, or in groups. Sharing results with the whole class is in some cases a prerequisite for proceeding with subsequent activities or questions.

Activities

Ask students to respond to the following:

1. Make a list of the influences that helped promote the development of science during the period from about 800 to 1800 CE, drawing on the information in the Student Handout. Ask students to remember that some influences affected science directly, others only indirectly. A unified consensus list, best arrived at in discussion, should be shared with the whole class. The questions could be restricted to the 1500-1800 period only.

2. If you were to classify the influences you have identified into groups, or categories according to some system, what principles of classification would you use? Why? For example, historical events could be grouped geographically, chronologically, or by the social class or religious group they affected, and so on. Make a note of the principles you came up with for categorizing influences on science.

3. Group the items on the list made in Activity 1 into three categories:

   A. Interaction with other people (not forgetting new institutions and ways for people to interact both with like-minded people and with people different from themselves)

   B. Contact with new ideas and information (not forgetting availability of ideas, spread of
I ideas, and reasons for acquiring or producing the ideas or information in the first place)

   C. Observation and management of what is in the physical environment (not forgetting technology and need for resources)

A unified consensus list of the items in each category, best arrived at in discussion, needs to be shared with the whole class.

4. Explain in what ways the items in each category helped promote the development of or changes in science. Explanations need to be shared with whole class.

5. Compare the principles of classification you have come up with yourselves in Activity 2 with those proposed for you in Activity 3. What advantages and disadvantages can you identify in each?

6. Label each entry on the Student Handout as A, B, or C, according to work done in Activity 2. What chronological changes and continuities in the kinds of things that influenced the development of or changes in science can you identify? Would more or different categories be helpful? If yes, what would they be? How would you account for any patterns you have found? This activity should start with individual work, followed by class discussion.

7. Taking any patterns of change and continuity you have identified in Activity 4 into account, divide the chronological list in the Student Handout into as many periods as seems to make sense, given your data. On what basis have you chosen where you are placing the dividing lines between periods? Why? This activity should start with individual work, followed by class discussion.

8. Compare the periodization you have formulated in Activity 5 with the periodization in your textbook. How would you explain similarities and differences? In discussion compare the advantages and disadvantages of the textbook's periodization with yours.

9. This activity may serve as assessment. The question could be restricted to the 1500-1800 period only. What do you consider the most important historical influences that helped promote the development of and changes in science during the period from about 800 to 1800 CE? Why? How did you decide what was important? Explain how each influence you identify affected science.

10. This activity may serve as assessment. Construct an argument that comes as close as you can to proving the following claim: "The most important positive influences on the cumulative development of science during the sixteenth-eighteenth centuries were the acquisition and spread of new information, and the cross-fertilization of ideas across geographic and cultural areas." Include an assessment of how close you have come to proving what you have set out to prove.

11. What characteristics that might be called scientific can you identify in the critical thinking skills you used in doing this unit? Explain. What critical skills typically associated with science were not used? Are the scientific skills you have just identified as missing from the unit characteristic of every science? In what sense can history be called a science? During this Activity, students might be reminded of Document P in the Lesson 2 Student Handout.

12. Thinking over the work done in this unit, how would you explain, in about five minutes, what science is to an interested fourth grader? Would your explanation differ from the one you recorded in reply to the first question in this unit's Introductory Activities? Why or why not?

How, if at all, has you understanding of the nature of science changed since the Introductory Activities in which you tried to put into words what was or was not science or scientific?

Extension

1. Evaluate the claim: "It was due to the developments in science during the millennium ending in 1800 that basic beliefs characteristic of our own times clearly took form." Support your argument with evidence.

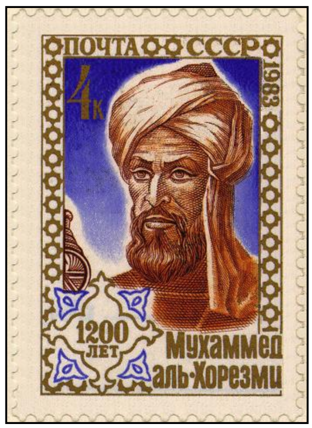
14. What is the defining characteristic of scientific truth–that is, how can one tell for sure what guarantees or proves that something can be accepted as true? Is there a difference between accepting something as true, and its actually being true? What other kinds of truths besides scientific ones might there be? What validations or guarantees are there, or could there be, for certain truth in non-scientific areas?

Lesson 3

Student Handout—What Influenced Science, and How?

The following list of influences is arranged in roughly chronological order.

Arabic numerals, including the zero, were developed in India. They were introduced to the Muslim world in the ninth century CE by al-Khwarizmi's book *The Hindu Art of Reckoning,* which explained how to use them for calculating without an abacus. Translated into Latin in the early twelfth century, the numbering system was introduced to Italy by a trader's son who had been sent to North Africa to learn mathematics around 1200. Zero did not come into widespread use in Europe until the seventeenth century.



Al-Khwarizmi (c. 780 – c. 850)
Muslim Mathematician born in Baghdad
USSR Stamp

Knowledge of paper-making reached Islam through Chinese prisoners of war in the tenth century. The first European paper mill operated in Italy in 1276. Germany and Italy were next in the fourteenth century.

In the ninth and tenth centuries the works of Greek philosophers, scientists, and mathematicians, as well as some works in Persian, Indian, and Chinese, were translated into Arabic, and commented upon by Muslim authors. In twelfth century Spain, scholars worked to translate these works from both Greek and Arabic into Latin.

The mariners' compass was probably introduced to Islam from China in the eleventh century, and was familiar to Christian sailors in the Mediterranean by the end of the twelfth.

In the twelfth century, some scholars, both Muslims and Christians, followed the school of thought holding that religion and philosophy were not incompatible when both were properly understood.

In twelfth and thirteenth century Europe, the rise of towns and longer-distance trade; the extension of royal power over wider geographical areas; and the establishment of universities contributed to the emergence of a literate class, the vast majority of whose members were monks, friars, clergy, or more rarely, nuns.

Both the churchmen who taught in Western universities and Muslim scholars had standard texts by Greek mathematicians, scientists, philosophers, and physicians, along Muslim commentaries of those works and original works by Muslims in Arabic. Ancient books by Euclid, Aristotle, Ptolemy, and Galen, as well as medieval texts by Ibn Sina (Avicenna from the eleventh century, and Ibn Rushd **(**Averroes)from the twelfth century CE, were pretty well obligatory reading for most Muslim and Christian students and scholars

Influenced by their reading of Greek philosophers, most Western scholars in the twelfth and thirteenth century held that that the universe was a rational and coherent whole, operating according to laws that God interfered with only exceptionally. Also, humans were able to use reason to understand and explain both nature and holy scripture. Some suggested that Bible passages contradicting reason or the natural order should not be taken literally.

Repeated decrees by various religious authorities forbidding the teaching of particular books or topics in the universities were not successful. While accepting the supremacy of theology and the Church, some scholars claimed that the spheres of religion and science were separate: "It is not the task of the Bible to teach us the nature of things; this belongs to philosophy."

In Europe by the mid-thirteenth century summaries became available of university masters' lectures and treatises, which dealt with topics in physics, astronomy, mechanics, cosmology and so on. These questions were hotly debated.

The presence of these subjects in the curriculum was voted on by the university faculties, because the universities were autonomous legal corporations with freedom to make decisions about their internal affairs, including what was to be taught.

Examples of block-printing probably reached Europe from China in the thirteenth century, stimulating great interest.

Cannons were used by both Muslim and European armies in the fourteenth century. Their use spread widely in the fifteenth century, increasing demand for iron and for ways to calculate the trajectory of cannonballs.

Mechanical, weight-driven clocks that precisely measured twenty-four equal hours of a day and night first appeared in the fourteenth century, and soon became widespread in Europe. They replaced earlier water-driven clocks that operated on hours of unequal length, depending as they did on a division of the day into 12 hours of light and 12 of dark, which differed in length seasonally and by latitude and which might freeze up in northern winter months.

In the fifteenth century Muslim scientists in Samarkand (in today's Uzbekistan) published new, more accurate astronomical tables, which were later introduced to Europe.

Humanism emerged in the fourteenth and fifteenth centuries among the urbanized and commercial inhabitants of north Italian city-states, The humanist movement started as an interest in Greek and Roman rhetoric, literature, and history. Humanists searched eagerly for forgotten and neglected manuscripts of classical authors, and they recovered a number of major Greek mathematical work. They were also interested in Hebrew mystical and occult writings, numerology, Hermetic magic, astrology, and alchemy.

Especially in Italy, the focus of humanist scholars was more on human achievement in this world than on salvation in the next. Believing in the dignity, abilities, and perfectibility of humans, they strongly advocated education, for high status women as well as for men.

In the later fourteenth and fifteenth centuries the overland access that European merchants had to East and Southeast Asia, owing partly to the existence of the Mongol empires, was mostly closed. This cut into the flow and added to the price of the luxury items like spices, silks, porcelain, and pearls. Affluent Europeans had gotten used to these products since the Crusades, but now had to buy them entirely through Muslim middlemen.

The power and prestige of the Roman Catholic Church declined in the fourteenth and fifteenth centuries owing to widespread abuses among church personnel, schism within the church, the election of multiple Popes, the spread of heresy, and kings' opposition to Papal authority. Secular rulers and governments made themselves stronger.

The Ottoman conquest of Constantinople in 1453 resulted in the flight west of Greek-speaking refugees who could serve as language teachers and translators. By 1500, many Italian humanists knew Greek. A new wave of translations began to make more Greek authors available in Latin, and especially Plato and his followers, who emphasized mathematical harmony in the universe.

Renaissance artists of the fifteenth-sixteenth centuries studied anatomy and optics to help represent their subject accurately. They formulated basic rules of linear perspective as a way to represent three-dimensional objects on a two-dimensional surface. They often worked as engineers as well as artists.

The invention of moveable metal type in Europe in the mid-fifteenth century (a technique devised earlier in China and Korea) led to mass production of identical books and pamphlets.

The first press in Rome produced 12,000 volumes in five years. By 1500, it was estimated that there were a thousand presses in 265 towns.

In the fifteenth century Portuguese and Spanish shipbuilders developed a new ship design, the caravel. It had high sides, a rounded profile, and a large cargo capacity. It required fewer hands to operate the rigging than did earlier designs. The triangular lateen sail, adapted from Arab models, allowed ships to tack against head winds.

Increasingly accurate maps were produced in Europe, influenced by Muslim maps and Ptolemy's second-century CE *Geography*, which had become available in Europe in the fourteenth century.

In the late fifteenth century Columbus concluded, based on a French philosopher's work, an Italian mathematician's map, and his own calculations drawn from Christian scripture, that the East Asian coast was only about 5000 miles from the west coast of Europe. (The actual distance is about 12,000 miles.)

In the early modern period, diversity of cultural background in the sources of knowledge and ideas continued. During the first 100 years of printing, some 10 percent of the authors of books on astronomy were Muslims. Chairs in Arabic and Hebrew were established in European universities in the fifteenth and sixteenth centuries. In the sixteenth and seventeenth centuries, some sixty editions of ibn Sina's *Canon of Medicine* (written about 1030 and translated into Latin in the twelfth century)were published in Europe. Among European scientific scholars Copernicus was a Pole, Kepler a German, Brahe a Dane, Galileo an Italian, Descartes a Frenchman, Newton an Englishman, Leeuwenhoek Dutch, and Franklin an American.

René Descartes (1596-1650)

French Mathematician, Scientist, and Philosopher

Engraving by W. Holl after painting by Franz Hals,

Prints & Photographs Division, Library of Congress LC-USZ62-61365

A number of the Greek works on mathematics recovered by humanists, including those of Archimedes, who was an engineer and inventor as well as mathematician in the third century BCE, were translated into Latin by the mid-sixteenth century. The professional teaching of mathematics spread in universities.

In the sixteenth century scholars used mathematics not only to describe, but to explain the workings of the physical world. They insisted on the physical truth of their mathematically derived theories, and they searched for physical causes to account for the mathematics.

Internal problems of the Catholic Church, the Protestant Reformation, and the increasing fragmentation of Protestant churches brought about increasing skepticism and questioning of previously accepted authorities and ideas.

Martin Luther, who triggered the Protestant Reformation in 1517, and his followers in the Protestant Reformation held that no one, neither Pope nor Church, had the authority to define true Christian belief. Individuals needed to read the Bible for themselves, and make their own interpretation guided by their conscience.

From the sixteenth century the spread of Reformation ideals, the growth of bureaucracies in centralizing monarchies, and the increase of global trade strengthened the demand for literacy, especially in northern Europe and among city populations generally.

In France, almost three times as many institutions of higher learning were founded between 1560 and 1650 as in all previous centuries. New universities were founded in Holland, Switzerland, Spain, Germany, Czechoslovakia, and Poland. French and English records show that a significant proportion of the students in schools, colleges, and universities came from merchant, shopkeeper, and artisan families, though only very rarely from peasant backgrounds.

An obtrusively bright supernova appeared among the fixed stars in 1573. Comets cut across the heavens in 1577, 1580, and 1585. Sunspots, the irregularity of the moon’s surface, and the moons of Jupiter, were observed in 1610.

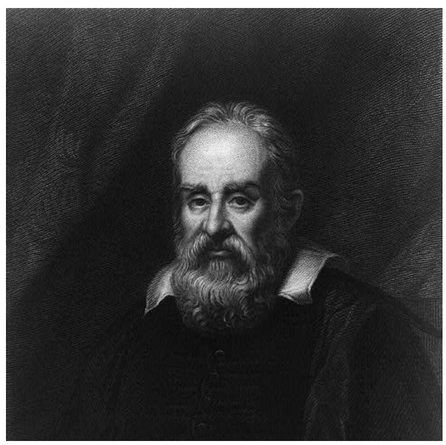
Following the European overseas voyages of discovery, the number of travelers increased significantly. Explorers, government officials, adventurers, merchants, mercenaries, and scientists visited faraway places on ships armed with cannon. Many wrote about their experiences, describing previously unknown lands, plants, animals, and peoples radically different from those hitherto known. Many botanical, zoological, and even human specimens were brought back to Europe, both as curiosities and for their potential usefulness.

From the sixteenth century increased demands for metals smelted with charcoal and for timber to build ships led to scarcity of wood, exhaustion of easily worked metal mines, opening of new mines for coal, the need for drainage in newly deep mines, and demands for improved mining machinery.

The English scholar Francis Bacon and his followers argued that the ability of science to produce useful knowledge and to further technological control of nature was taken as proof of its truth.

The mathematical notations "+" and "=" were introduced in the mid-1500's. About a hundred years later, so were the signs for multiplication and division. Coordinates, and the use of the letters "a, b, c" for known, and of "x, y, z" for unknown mathematical quantities, also came into use. Negative and imaginary numbers, the calculus of probabilities, decimals, logarithms, and infinitesimal calculus were invented during the seventeenth century.

A number of scientists in the sixteenth and seventeenth centuries were concerned about their ideas getting them into trouble with the Church. Bruno and Galileo were actually tried for heresy and convicted. Some other scholars were imprisoned. But there was no strong, concentrated, successful religious suppression of scientific ideas.



Galileo Galilei (1564-1642)
Italian Natural Philosopher, Astronomer, and Mathematician
Engraved by Robt. Hart from a Picture by Ramsay in Trinity College, Cambridge.
Prints & Photographs Division, Library of Congress, LC-USZ62-7923

The existence and enforcement of censorship affecting the publication of scientific ideas varied by country. It was typically intermittent and inconsistently stringent, continuing so through the eighteenth century.

The Royal Society For the Improvement Of Natural Knowledge By Experiment was founded in London in1662. Also in England the Ordnance Office (equivalent of the Pentagon) paid the salary of the chief Astronomer, called the Astronomer Royal. Louis XIV generously funded the French Royal Academy Of Sciences. Scientific Academies were also publicly funded in Berlin and St. Petersburg.

By 1750 “philosophical societies” dedicated to research, experiment, and publication of results, were a regular feature of even provincial towns in England, France, Italy, Germany, and Holland.

Several members of the Royal Society continued in the seventeenth century to defend in writing the existence of demons, witches, and “intelligences” that animated stars.

Precision instruments specifically for scientific use were invented, such as the telescope, microscope, barometer, thermometer, air pump, pendulum clock, and spring watch. Most scientists made their own instruments until a body of craftsmen grew up who could work on the frontiers of precision technology.

Exchanges of ideas in Europe occurred in private correspondences and in the journals of the scientific societies. An increasingly interested upper and middle class public had the opportunity to learn and talk about science in salons, reading clubs, and coffee houses. In the 1660’s, one French author claimed to have identified 251 women in Paris who were hostesses of salons. Many scientists tried deliberately to write in ways that would make their work accessible to non-scientists, and spread the word in public lectures as well as in correspondence and in print. (seventeenth and eighteenth centuries)

From the early eighteenth century, a growing population was seen as vital to a state’s future, so governments got into statistical estimations of the rates of birth, death, marriage and so on. States also funded environmental studies of what made places healthy to live in.

Publications and literacy spread in the eighteenth century. In Britain twenty-five periodicals were published in 1700 and 158 in 1780. The first daily newspaper was published in London in 1702. In 1780, 37 English towns had daily newspapers. In France, 30 titles were published yearly in 1750 and 1,600 in the 1780’s. By that time literacy rates there had risen to 47 percent among men, 27 percent among women.

Intellectuals of the eighteenth century Enlightenment, known as *philosophes*, believed they could extend to the study of human behavior the use of the scientific method [to them, mostly reason backed by evidence]. Their emphasis was on the “science of man” [what we would call the social sciences]; and they studied society mostly in order to change it. They popularized scientific ideas and knowledge for the new reading public, believed that change would lead to progress, and questioned both tradition and authority. Many were anti-clerical, and some anti-religion.

At the end of the eighteenth century the French government held the first international scientific conference, intended to come up with a uniform, universal system of measurement. The collaborative efforts of 19 participants from France, Denmark, the Netherlands, Switzerland, Italy, and Spain produced the standard meter (a measured portion of the earth’s circumference), the liter (contents of a cube one-tenth of a meter on each side), and other decimal measures to replace the thousands of different measurement units current in France, let alone elsewhere, at the time.

In 1760 John Harrison, an English craftsman, produced H-4, a watch for keeping precise time at sea and therefore for measuring longitude.

This unit and the Three Essential Questions

HUMANS & the ENVIRONMENT	In what ways might the new science of the seventeenth and eighteenth centuries have affected the physical and natural environment? In what ways does science affect the environment, for good or ill, today?
HUMANS & other HUMANS	Do you or family members belong to any organizations having a major aim of sharing scholarly, technical, scientific, business, or artistic information? Why are organized networks for sharing information useful? Research the organization, purposes, and activities of the English Royal Society, which was founded in the seventeenth century.
HUMANS & IDEAS	“Dare to know!” was the motto of the Enlightenment. Could this motto have served the scientific revolution as well? Why or why not?

This unit and the Seven Key Themes

This unit emphasizes:

Key Theme 6: Science, Technology, and the Environment

Key Theme 7: Spiritual Life and Moral Codes

This unit and the Standards in Historical Thinking

Historical Thinking Standard 1: Chronological Thinking

The student is able to (E) interpret data presented in time lines and create time lines by designating appropriate equidistant intervals of time and recording events according to the temporal order in which they occurred

Historical Thinking Standard 2: Historical Comprehension

The student is able to (F) appreciate historical perspectives—(a) describing the past on its own terms, through the eyes and experiences of those who were there, as revealed through their literature, diaries, letters, debates, arts, artifacts, and the like; (b) considering the historical context in which the event unfolded--the values, outlook, options, and contingencies of that time and place; and (c) avoiding "present-mindedness," judging the past solely in terms of present-day norms and values.

Historical Thinking Standard 3: Historical Analysis and Interpretation

The student is able to (E) distinguish between unsupported expressions of opinion and informed hypotheses grounded in historical evidence.

Historical Thinking Standard 4: Historical Research Capabilities

The student is able to (A) formulate historical questions from encounters with historical documents, eye-witness accounts, letters, diaries, artifacts, photos, historical sites, art, architecture, and other records from the past.

Historical Thinking Standard 5: Historical Issues-Analysis and Decision-Making

The student is able to (A) identify issues and problems in the past and analyze the interests, values, perspectives, and points of view of those involved in the situation.

Resources for Teachers and Students

Alavi, Karima, and Susan L. Douglass, *Emergence of Renaissance: Cultural Interactions between Europeans and Muslims*. Fountain Valley, CA: Council on Islamic Education, 1999. http://www.cie.org. Segments II (Education and Scholarship) and III (Science and Technology) are relevant to this unit.

Frick, Carole Collier, *The Scientific Revolution*. Los Angeles: National Center for History in the Schools. This unit invites the student to explore the advances in scientific knowledge made in Europe in the mid-sixteenth century, which radically changed humankind's basic notions of the very structure of the universe. Students are introduced to the contributions of key scientists and to their basic discoveries and inventions, through illustrations and short excerpts of their work.

Hellyer, Marcus ed. *The Scientific Revolution: The Essential Readings*. Oxford: Blackwell Publishing, 2003. For those wishing to delve more deeply and be exposed to some historiography. Chapters on individual topics, though short, touch on main issues. Their one-page introductions helpfully summarize their argument. Style is clear and to the point.

Grant, Edward. *The Foundations of Modern Science in the Middle Ages: Their Religious, Institutional, and Intellectual Contexts.* Cambridge: Cambridge UP, 1996. Great source of scholarly information, but heavy-going; more detail than most would want.

Gribbin, John. *Science: A History*. London: Penguin Books, 2003. Reader-friendly survey starting with Copernicus and limited to Europe. Excellent on, but restricted to, the science and scientists, including fascinating biographical details.

Henry, John. *The Scientific Revolution and the Origins of Modern Science*. New York: St. Martin's Press, 1997. Concise 96-page treatment mostly outlines scientific method; mechanical philosophy; relationship between magic and science, and religion and science. Necessarily lacks depth, but worthwhile as brief intelligent overview.

Huff, Toby E. *An Age of Science & Revolutions, 1600-1800*. The Medieval and Early Modern World. Oxford: Oxford UP, 2005.

Huff, Toby E. *The Rise of Early Modern Science: Islam, China, and the West.* Cambridge: Cambridge UP, 1993. Author's focus is on why modern science arose in the West. He deals usefully with religious, legal, educational, and scientific institutions, which he examines and compares in Islam and the West. Often sociological perspective adds interest and depth to his analysis of science's development and its background, but this can be a distraction.

Jacob, Margaret. *The Cultural Meaning of the Scientific Revolution*. Philadelphia: Temple UP, 1988.

Jardine, Lisa. *Ingenious Pursuits: Building the Scientific Revolution*. New York: Anchor Books, 1999. Starting in late seventeenth century, author explores motivations of scientists, their relations with each other, and non-technical details on how exactly they did science. Frequent quotations from original sources and many illustrations. Mature able students could be assigned sections of it to read.

McClellan, James E., III, and Harold Dorn. *Science and Technology in World History: An Introduction*. Baltimore: Johns Hopkins UP, 1999. Winner of the World History Association best book award.

Nasr, Seyyed Hossein. *Islamic Science*: *An Illustrated Study.* World of Islam Festival Publishing: Kent, UK: 1976. Splendid, helpful, intriguing illustrations, from models of planetary motion and macrocosm/microcosm correspondences to scientific instruments, development of Arabic numerals, maps, and much else. Text more detailed than most would want.

_____. *Science and Civilization In Islam*. Cambridge, MA: Harvard UP, 1968. Considers Muslim science in the context of religious beliefs and sets out his arguments by dealing with individual sciences in turn. Valuable for many excerpts from one page to several from original sources.

Osler, Margaret J. ed. *Rethinking the Scientific Revolution*. Cambridge: Cambridge UP, 2000. First and last chapters give good account of the questioning and defense of the concept of a "scientific revolution," how the dominance of the concept came about, and reasons for its continuing usefulness. The rest too detailed and technical to be useful at pre-collegiate level.

Shapin, Steven. *The Scientific Revolution*. Chicago: University of Chicago Press, 1996. Provocative, unusual, and readable, yet still within mainstream scholarship. Analyzes concept of the scientific revolution for validity and examines in the historical context.

Turner, Howard R. *Science in Medieval Islam: An Illustrated Introduction*. Austin: University of Texas Press, 1995.

Sources of Documents in the Student Handouts

Andrea, Alfred J. and James H. Overfield, eds. *The Human Record: Sources of Global History*. Vol. 2. Boston: Houghton Mifflin, 1990.

Becker, Carl L. *The Heavenly City of Eighteenth-Century Philosophers*. New Haven: Yale UP, 1932.

Burnett, Charles, ed. and trans. *Adelard of Bath: Conversation With His Nephew*. Cambridge: Cambridge UP, 1998.

Clagett, Marshall. *The Science of Mechanics In the Middle Ages*. Madison: University of Wisconsin Press, 1957.

Danielson, Dennis Richard. *The Book of the Cosmos*. Cambridge, MA: Perseus Publishing, 2000.

Dear, Peter, ed. *The Scientific Enterprise in Early Modern Europe: Readings From Isis.* Chicago: University of Chicago Press, 1997.

Gay, Peter, ed. *The Enlightenment: A Comprehensive Anthology*. New York: Simon and Schuster, 1973.

Gilbert, William. *On the Loadstone and Magnetic Bodies, and On the Great Magnet the Earth.* Trans. P. Fleury Mottelay. New York: John Wiley and Sons, 1893.

Grant, Edward ed. *A Source Book In Medieval Science*. Cambridge, MA: Harvard UP, 1974.

Guskin, Phyllis J. "The Context of Witchcraft." *Eighteenth Century Studies* 15 (1981): 58.

Hill, Donald R. *Islamic Science and Engineering*. Edinburgh: Edinburgh UP, 1993.

Klemm, Friedrich. *A History of Western Technology*. Trans. D. W. Singer. New York: Charles Scribner's Sons, 1959.

Redi, Francesco. *Experiments On the Generation of Insects*. Trans. M. Bigelow. Chicago: Open Court Publishing Company, 1909.

Webster, H. *Historical Selections*. Boston: D. C. Heath, 1929.

Conceptual links to other teaching units

The Scientific Revolution represented a challenge to traditional religious explanation of nature and the cosmos. In the same era, however, all the world's major religions remained vital. In Europe major religious change occurred simultaneously with new developments in scientific thought. The Roman Catholic Church lost its monopoly of Christian teaching and worship in western and central Europe as new Protestant dominations rejected the authority of the Pope and offered a variety of new Christian doctrines and practices. At the same time Christianity continued to spread in the world, notably in the Americas. In Afroeurasia, Islam made millions of new converts in Africa and Asia.