SECTION 5

An 1800s artist imagines Galileo at work, peering into the sky. Galileo's telescope is shown at top right.

WITNESS HISTORY AUDIO

Mountains on the Moon

In 1609, Italian astronomer Galileo Galilei heard of a new Dutch invention, the telescope. It was designed to help people see distant enemy ships. Galileo was interested for another reason—he wondered what would happen if he trained a telescope on the night sky. So he built his own telescope for this purpose. When he pointed it at the sky, he was amazed. The new telescope allowed him to see mountains on the moon, fiery spots on the sun, and four moons circling the planet Jupiter. "I did discover many particulars in Heaven that had been unseen and unheard of until this our age," he later wrote.

Focus Question How did discoveries in science lead to a new way of thinking for Europeans?

The Scientific Revolution

Objectives

- Explain how new discoveries in astronomy changed the way people viewed the universe.
- Understand the new scientific method and how it developed.
- Analyze the contributions that Newton and other scientists made to the Scientific Revolution.

Terms, People, and Places

Nicolaus Copernicus
heliocentric
Tycho Brahe
Johannes Kepler
Galileo
Francis Bacon
René Descartes
scientific method
hypothesis
Robert Boyle
Isaac Newton
gravity
calculus

Note Taking

Reading Skills: Identify Main Ideas Use a table like the one below to record information about important people of the Scientific Revolution.

Thinkers of the Scientific Revolution	
Nicolaus Copernicus	Developed sun-centered universe theory

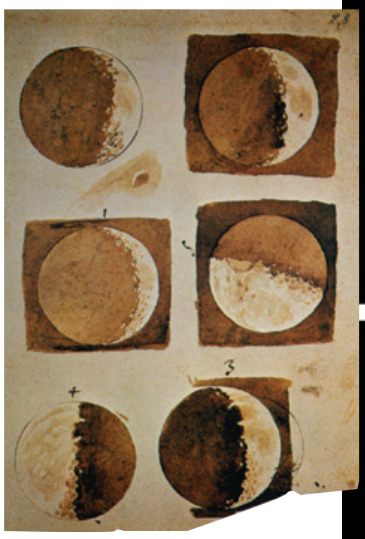
The Renaissance and the Reformation facilitated the breakdown of the medieval worldview. In the mid-1500s, a profound shift in scientific thinking brought about the final break with Europe's medieval past. Called the Scientific Revolution, this movement pointed toward a future shaped by a new way of thinking about the physical universe. At the heart of the Scientific Revolution was the assumption that mathematical laws governed nature and the universe. The physical world, therefore, could be known, managed, and shaped by people.

Changing Views of the Universe

Until the mid-1500s, Europeans' view of the universe was shaped by the theories of the ancient writers Ptolemy and Aristotle. More than 1,000 years before the Renaissance, they had taught that Earth was the center of the universe. Not only did this view seem to agree with common sense, it was accepted by the Church. In the 1500s and 1600s, however, people began to question this view.

Copernicus Challenges Ancient Astronomy In 1543, Polish scholar **Nicolaus Copernicus** (koh PUR nih kus) published *On the Revolutions of the Heavenly Spheres*. In it, he proposed a **heliocentric,** or sun-centered, model of the universe. The sun, he said, stands at the center of the universe. Earth is just one of several planets that revolve around the sun.

Most experts rejected this revolutionary theory. In Europe at the time, all scientific knowledge and many religious teachings were based on the arguments developed by classical thinkers. If Ptolemy's reasoning about the planets was wrong, people believed, then the whole system of human knowledge might be called into question. But in the late 1500s, the Danish astronomer **Tycho Brahe** (TEE koh BRAH uh) provided evidence that supported Copernicus's theory. Brahe set up an astronomical observatory. Every night for years, he carefully observed the sky, accumulating data about the movement of the heavenly bodies.



Views of the Moon
Galileo sketched the views of the moon he saw through his telescope in 1609 (left). Pictures of the moon taken through a modern telescope (right) look remarkably similar.

After Brahe's death, his assistant, the brilliant German astronomer and mathematician **Johannes Kepler,** used Brahe's data to calculate the orbits of the planets revolving around the sun. His calculations supported Copernicus's heliocentric view. At the same time, however, they showed that each planet does not move in a perfect circle, as both Ptolemy and Copernicus believed, but in an oval-shaped orbit called an ellipse.

Galileo's "Heresies" Scientists from many different lands built on the foundations laid by Copernicus and Kepler. In Italy, **Galileo** Galilei assembled an astronomical telescope. As you have read, he observed that the four moons of Jupiter move slowly around that planet—exactly, he realized, the way Copernicus said that Earth moves around the sun.

Galileo's discoveries caused an uproar. Other scholars attacked him because his observations contradicted ancient views about the world. The Church condemned him because his ideas challenged the Christian teaching that the heavens were fixed in position to Earth, and perfect.

Vocabulary Builder
contradict—(kahn truh DIKT) *v.* to go against

In 1633, Galileo was tried before the Inquisition, and for the rest of his life he was kept under house arrest. Threatened with death unless he withdrew his "heresies," Galileo agreed to state publicly in court that Earth stands motionless at the center of the universe. Legend has it that as he left the court he muttered, "And yet it moves."

Checkpoint **Why was Copernicus's theory seen as radical?**

A New Scientific Method

Despite the opposition of the Church, by the early 1600s a new approach to science had emerged, based upon observation and experimentation. During the Renaissance, the works of the ancient Greek philosopher Plato were rediscovered. Plato taught that man should look beyond simple appearances to learn nature's truths. He believed that mathematics, one of the greatest human achievements, was the key to learning these truths. His teachings were rediscovered by Renaissance scientists and helped shape people's view of the physical world.

Vocabulary Builder
philosopher—(fih LAHS uh fur) *n.* a person who is an expert in the study of knowledge

Bacon and Descartes: Revolutionary Thinkers The new scientific method was really a revolution in thought. Two giants of this revolution were the Englishman **Francis Bacon** and the Frenchman **René Descartes** (day KAHRT). Each devoted himself to understanding how truth is determined. Both Bacon and Descartes, writing in the early 1600s, rejected Aristotle's scientific assumptions. They also challenged the scholarly traditions of the medieval universities that sought to make the physical world fit in with the teachings of the Church. Both argued that truth is not known at the beginning of inquiry but at the end, after a long process of investigation.

Bacon and Descartes differed in their methods, however. Bacon stressed experimentation and observation. He wanted science to make life better for people by leading to practical technologies. Descartes emphasized human reasoning as the best road to understanding. In his *Discourse on Method* (1637), he explains how he decided to discard all traditional authorities and search for provable knowledge. Left only with doubt, he concluded that doubt was the only thing he could not question, and that in order to doubt he had to exist as a rational, thinking being. Therefore he made his famous statement, "I think, therefore I am."

A Step-by-Step Process Over time, a step-by-step process of discovery evolved that became known as the **scientific method.** The scientific method required scientists to collect and accurately measure data. To explain the data, scientists used reasoning to propose a logical **hypothesis,** or possible explanation. They then tested the hypothesis with further observation or experimentation. Mathematical calculations were used to convert the observations and experiments into scientific laws. After reaching a conclusion, scientists repeated their work at least once—and usually many times—to confirm and refine their hypotheses or formulate better ones.

Checkpoint **How did Bacon and Descartes each approach the new scientific method?**

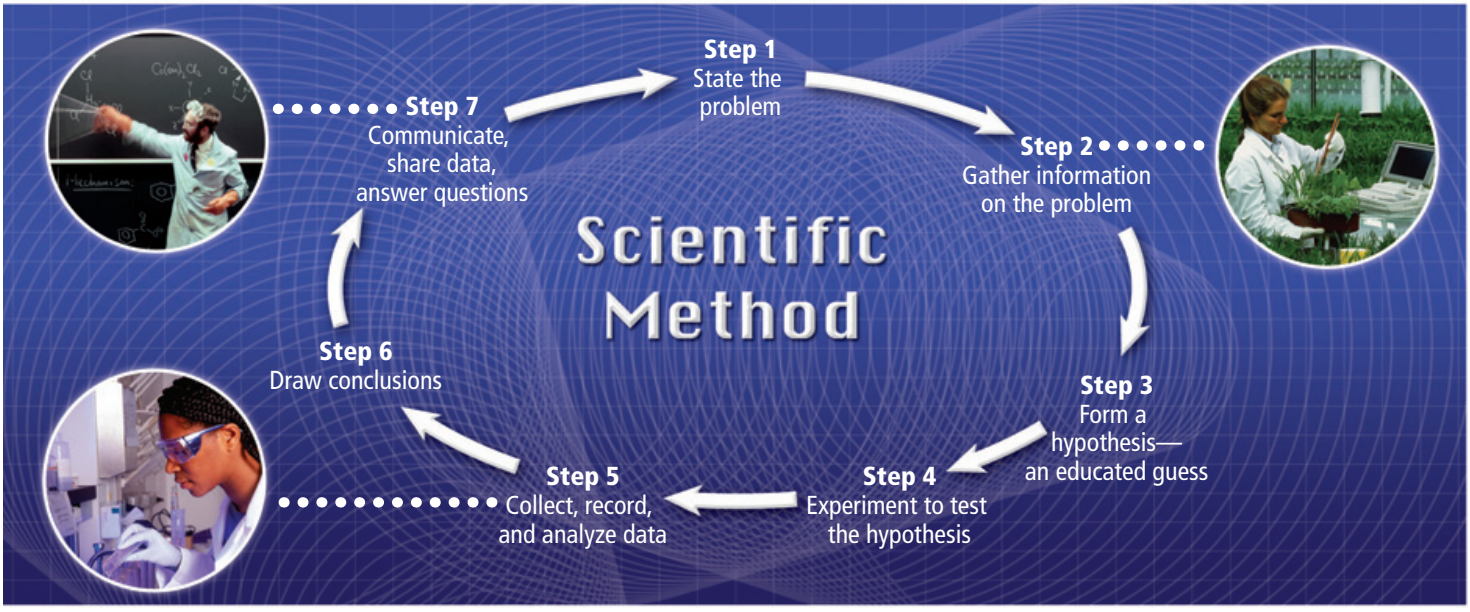
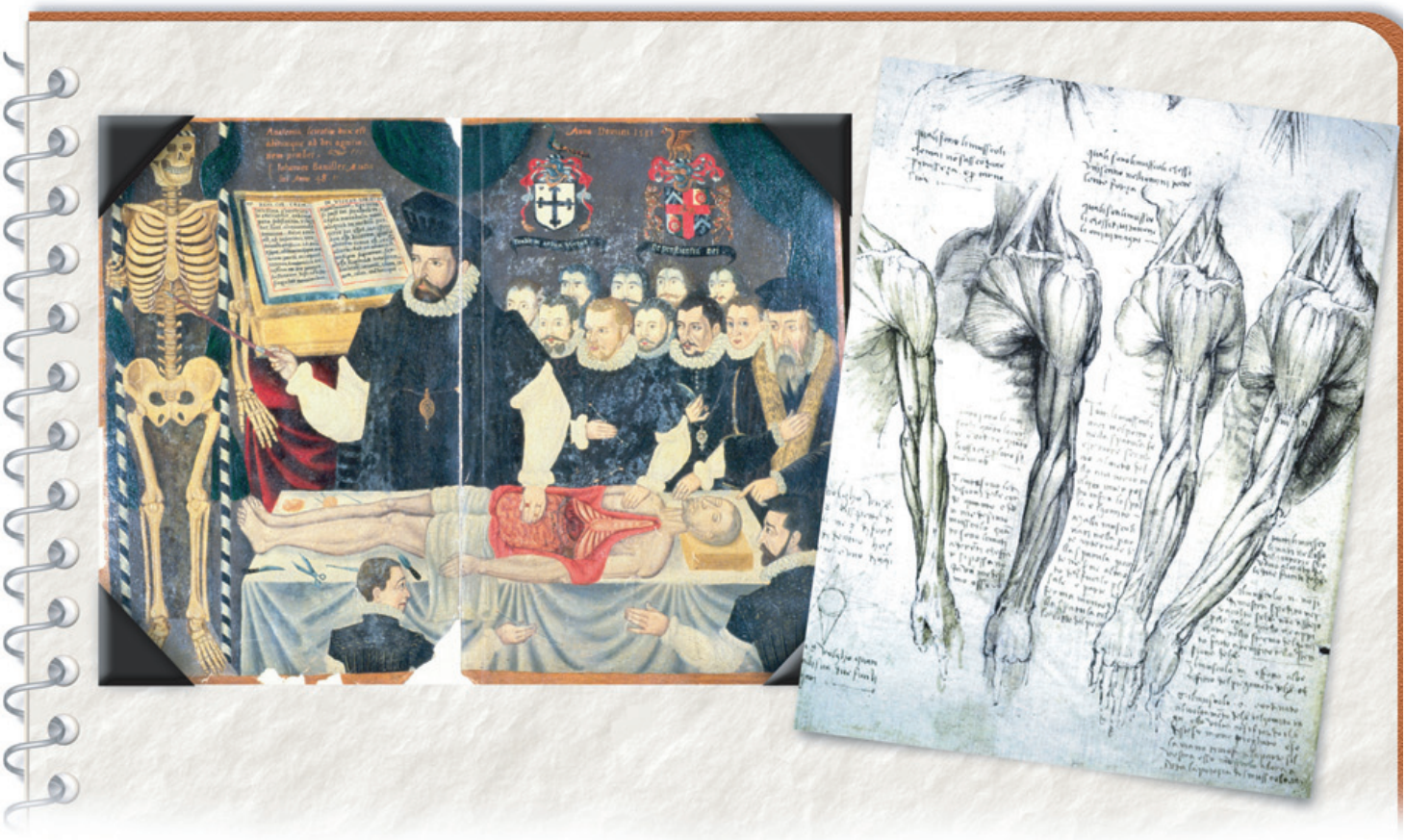


Diagram Skills The scientific method, still used today, is based on careful observation and measurement of data. *Why is Step 7 an important part of the process?*



Human Anatomy
Renaissance artists and scientists, determined to learn how things really worked, studied nature with great curiosity. In the 1400s, Leonardo drew the muscles of the human arm with amazing accuracy (right). Renaissance doctors learned much about human anatomy from dissections (left). *How does this painting from the 1500s reflect the advances in scientific thinking?*

Breakthroughs in Medicine and Chemistry

The 1500s and 1600s saw dramatic changes in many branches of science, especially medicine and chemistry. The rapid changes in science and technology that began in this period still continue to this day.

Exploring the Human Body Medieval physicians relied on the works of the ancient physician Galen. Galen, however, had made many errors, in part because he had limited knowledge of human anatomy. During the Renaissance, physicians made new efforts to study the human body. In 1543, Andreas Vesalius (vuh SAY lee us) published *On the Structure of the Human Body,* the first accurate and detailed study of human anatomy. Vesalius used whatever means he could to increase his knowledge of anatomy. He used friendships with people of influence to get invitations to autopsies. He also autopsied bodies that he himself obtained—counting on friends in the local government to look the other way.

In the early 1540s, French physician Ambroise Paré (pa RAY) developed a new and more effective ointment for preventing infection. He also developed new surgical techniques, introduced the use of artificial limbs, and invented several scientific instruments. Then in the early 1600s, William Harvey, an English scholar, described the circulation of the blood for the first time. He showed how the heart serves as a pump to force blood through veins and arteries. Later in the century, the Dutch inventor Anton van Leeuwenhoek (LAY wun hohk) perfected the microscope and became the first human to see cells and microorganisms. These pioneering scientists opened the way for further discoveries.

An English poet wrote the following as an epitaph for Newton's gravestone. What does it suggest about how people of the time viewed Newton's importance?

Primary Source

"Nature and Nature's Laws lay hid in night,
God said, Let Newton be! and all was light."
—Alexander Pope, *Epitaphs*

Transforming Chemistry The branch of science now called chemistry was in medieval times called alchemy. Alchemists believed that any substance could be transformed into any other substance, and many of them tried unsuccessfully to turn ordinary metals into gold. With the advances of the Scientific Revolution, the experiments of alchemists were abandoned. However, some of their practices—especially the manipulation of metals and acids—set the stage for modern chemistry.

In the 1600s, English chemist **Robert Boyle** refined the alchemists' view of chemicals as basic building blocks. He explained all matter as being composed of tiny particles that behave in knowable ways. Boyle distinguished between individual elements and chemical compounds, and explained the effect of temperature and pressure on gases. Boyle's work opened the way to modern chemical analysis of the composition of matter.

Checkpoint How did Boyle transform the science of chemistry?

Isaac Newton Links the Sciences

As a student in England, **Isaac Newton** devoured the works of the leading scientists of his day. By age 24, he had formed a brilliant theory to explain why the planets moved as they did. According to one story, Newton saw an apple fall from a tree. He wondered whether the force that pulled that apple to Earth might not also control the movements of the planets. In the next 20 years, Newton perfected his theory. Using mathematics, he showed that a single force keeps the planets in their orbits around the sun. He called this force **gravity.**

In 1687, Newton published a book explaining the law of gravity and other workings of the universe. Nature, argued Newton, follows uniform laws. All motion in the universe can be measured and described mathematically. To many, Newton's work seemed to link the sciences just as gravity itself bound the universe together.

For more than 200 years, Newton's laws held fast. In the early 1900s, startling new theories of the universe called some of his ideas into question. Yet his laws of motion and mechanics continue to have many practical uses. For example, **calculus**—a branch of mathematics partially developed by Newton and used to explain his laws—is still applied today.

Checkpoint How did Newton use observations of nature to explain the movements of the planets?

SECTION 5 Assessment

Progress Monitoring *Online*
For: Self-quiz with vocabulary practice
Web Code: naa-1351

Terms, People, and Places

1. What do all of the key people listed at the beginning of this section have in common? Explain.

Note Taking

2. **Reading Skill: Identify Main Ideas** Use your completed table to answer the Focus Question: How did discoveries in science lead to a new way of thinking for Europeans?

Comprehension and Critical Thinking

3. **Recognize Ideologies** Why did the theories of Copernicus and Galileo threaten the views of the Church?
4. **Make Generalizations** In what ways did the scientific method differ from earlier approaches to learning?
5. **Recognize Cause and Effect** What impact did Renaissance ideas have on medicine?
6. **Synthesize Information** How did Newton use the ideas of Plato?

Writing About History

Quick Write: Write a Conclusion Write a conclusion to a persuasive essay about the Scientific Revolution. Your conclusion should restate a thesis statement, supported by one or two strong arguments. You may want to end your essay with a quotation. For example, you could use the Pope quotation to support a thesis that Newton's ideas were the most important of the Scientific Revolution.

Chapter Assessment

Terms, People, and Places

Complete each sentence by choosing the correct answer from the list of terms below. You will not use all of the terms.

patron	indulgence	ghetto
humanism	predestination	heliocentric
vernacular	compromise	hypothesis
utopian		

1. Lorenzo de' Medici was a _____ of the Florentine arts.
2. Rabelais and Shakespeare wrote in the _____ to appeal to the common people.
3. Calvin's belief in _____ set him apart from Catholics.
4. Elizabeth's sensible _____ helped keep England unified in the face of religious conflict.
5. Copernicus's _____ theory of the universe challenged the accepted teachings of the Church.

Main Ideas

Section 1 (pp. 410–417)

6. How did the new Renaissance worldview shape the work of Italian Renaissance artists and writers?

Section 2 (pp. 418–422)

7. What was the role of the printing press in spreading Renaissance ideas?
8. How did northern European artists and writers apply Renaissance ideas in their work?

Section 3 (pp. 423–427)

9. How did the Renaissance open the door to the Protestant Reformation?

Section 4 (pp. 428–433)

10. Why did the Church respond with its Catholic Reformation?

Section 5 (pp. 434–439)

11. How were the scientists of the Scientific Revolution influenced by Renaissance ideas?

Chapter Focus Question

12. How did the Renaissance shape European art, thought, and religion?

Critical Thinking

13. **Geography and History** How did Italy's geography encourage the spread of the Renaissance?
14. **Analyze Information** In what ways was the Renaissance a break with medieval times? In what ways was it a continuation of medieval times?
15. **Predict Consequences** Under what circumstances are religious beliefs likely to inspire anger or violence?
16. **Analyze Visuals** What Renaissance theme does the bas-relief below express?

17. **Test Conclusions** The Renaissance and Scientific Revolution are often described as eras of human progress. Evaluate whether this is an accurate description.
18. **Recognize Cause and Effect** Why did England escape the kinds of religious wars that tore apart other European nations?
19. **Synthesize Information** An English author wrote, "The preaching of sermons is speaking to a few of mankind, but printing books is talking to the whole world." How does this statement suggest a relationship between two of the key events discussed in this chapter?

Writing About History

In this chapter's five Section Assessments, you developed skills for writing a persuasive essay.

Writing a Persuasive Essay European history from 1300 to the 1600s was a time of great change, discovery, and religious upheaval. Write a persuasive essay that presents your position on either the Renaissance, the Reformation, or the Scientific Revolution.

Prewriting

- Choose a topic and decide what your main position will be.
- Think of arguments that both support and oppose your position.
- Gather evidence that supports your position.

Drafting

- State your position in a thesis statement.
- Organize your arguments into a draft outline.
- Write the introduction, body text, and closing arguments. Be sure to support your arguments with a variety of points, including facts, comparisons, and statistics.

Revising

- Use the guidelines for revising your report on page SH17 of the Writing Handbook.

Document-Based Assessment

The Impact of the Printing Press

In a time when new ideas and discoveries were commonplace, the invention of the printing press was no less than astonishing in its impact. Documents A, B, and D describe the spread of printing during the Renaissance. Document C, written by a historian in the 1500s, describes its impact at the time.

Document A

"In 1455 all Europe's printed books could have been carried in a single wagon. Fifty years later, the titles ran to tens of thousands, the individual volumes to millions. Today, books pour off presses at the rate of 10,000 million *a year.* That's some 50 million tons of paper. Add in 8,000 to 9,000 daily newspapers, and the Sundays, and the magazines, and the figure rises to 130 million tons . . . It would make a pile 700 meters [2,297 feet] high—four times the height of the Great Pyramid."

—From ***Gutenberg: How One Man Remade the World with Words*** by John Man

Document B

"Printing spread from Mainz to Strasbourg (1458), Cologne (1465), Augsburg (1468), Nuremberg (1470), Leipzig (1481), and Vienna (1482). German printers, or their pupils, introduced the 'divine' art to Italy in 1467, Switzerland and Bohemia in 1468, France and the Netherlands in 1470, Spain, England, Hungary, and Poland between 1474 and 1476, Denmark and Sweden in 1482–1483. By 1500 the presses had issued about six million books in approximately forty thousand editions, more books, probably, than had been produced in western Europe since the fall of Rome . . . Now individuals could afford to own books, where before they had normally been owned almost exclusively by institutions—monasteries, cathedral chapters, and colleges."

—From ***The Foundation of Early Modern Europe, 1460–1559*** by Eugene F. Rice, Jr.

Document C

"As if to offer proof that God has chosen us to accomplish a special mission, there was invented in our land a marvelous new and subtle art, the art of printing. This opened German eyes even as it is now bringing enlightenment to other countries. Each man became eager for knowledge, not without feeling a sense of amazement at his former blindness."

—From ***Address to the Estates of the Empire*** by Johann Sleidan

Document D

The Spread of Printing in Renaissance Europe

Analyzing Documents

Use your knowledge of the Renaissance and Documents A, B, C, and D to answer questions 1–4.

1. According to Document B, the increased supply and lower cost of books had what effect?
   - **A** More people became teachers.
   - **B** More people became printers.
   - **C** More people bought books.
   - **D** More people bought printing presses.

2. What information about printing can be found only on Document D?
   - **A** specific dates when printing presses were introduced
   - **B** areas where the concentration of printing presses was densest
   - **C** numbers of printing presses introduced into selected cities
   - **D** countries where printing presses were introduced

3. What does German historian Sleidan, in Document C, imply is the *most important* role of the printing press?
   - **A** spreading the Protestant religion
   - **B** teaching German history to other countries
   - **C** making books cheaper
   - **D** giving Germans more knowledge

4. **Writing Task** How did the invention of the printing press affect the spread of the Reformation? Use specific evidence from the documents above, along with information from this chapter, to support your answer.