The ancient Greek astronomer Ptolemy believed that the Earth was at the center of the universe and the sun and stars revolved around it. This is an image of Ptolemy's Geocentric Universe.

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Both the Renaissance and the Reformation looked to the past for models. Humanists turned to ancient classical learning. Religious reformers looked to the Bible and early Christian times for inspiration. The Renaissance spirit of inquiry led scientists to explore beyond the knowledge of the ancients.

Interactive Flipped Video

>> Objectives

Explain how new discoveries in astronomy changed the way people viewed the universe.

Understand the new scientific method and how it developed.

Identify the contributions that Galileo, Copernicus, Newton, and other scientists made to the Scientific Revolution.

>> Key Terms

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

The Scientific Revolution

Changing Views of the Universe

Beginning in the 1500s, profound changes took place in the sciences that pointed toward a future shaped by a new way of thinking about the physical universe. These new understandings about the physical world became part of what is now called the Scientific Revolution.

Old Views Until the mid-1500s, European scholars accepted the ideas set out by ancient Greek thinkers like Aristotle. The Greek astronomer Ptolemy had taught that Earth was the center of the universe.

European scholars long accepted this view because it seemed to agree with common sense. It also followed the teachings of the Church. In the 1500s and 1600s, startling discoveries radically changed the way Europeans viewed the physical world.

Copernicus Offers a New Theory 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, which contradicted both Church teachings and the teachings of Ptolemy. In Europe, 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, then the whole system of human knowledge might be called into question.

In the late 1500s, the Danish astronomer **Tycho Brahe** (TEE koh BRAH uh) provided evidence to support 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.

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.

The Church Rejects Galileo's Discoveries

Scientists from many different lands built on the work of Copernicus and Kepler. In Italy, **Galileo Galilei** used new technology to assemble an astronomical telescope. With this instrument he became the first person to see mountains on the moon. 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, unmoving, and perfect.

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

? ANALYZE INFORMATION Why were the discoveries of astronomers like Galileo seen as radical and a threat to Church authority?

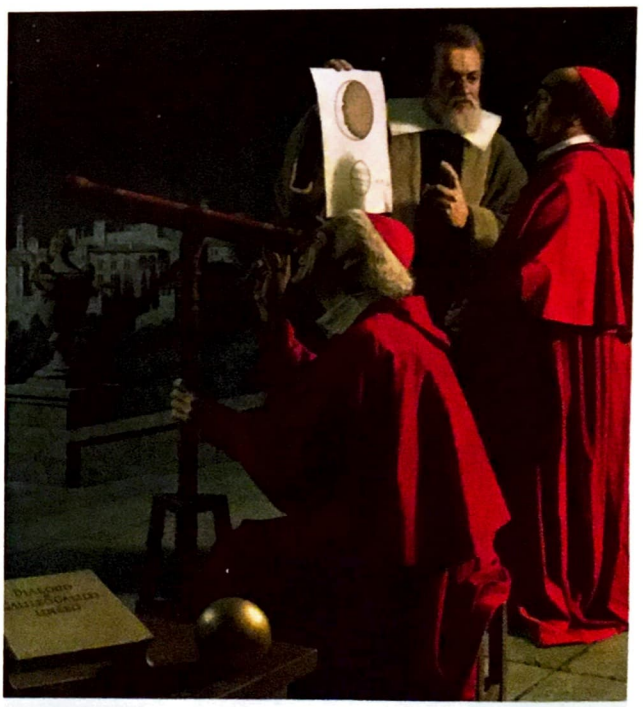
A New Scientific Method

Despite the opposition of the Church, by the early 1600s a new approach to science had emerged. Unlike most earlier approaches, it started not with Aristotle or Ptolemy or even the Bible but with observation and experimentation. Most important, complex mathematical calculations were used to convert the observations and experiments into scientific laws. In time, this approach became known as the **scientific method.**

Revolutionary Scientific 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 medieval scholars who 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.



>> Galileo explains to skeptical church officials that the moon's phases reflect its relation to the earth and the sun. Galileo studied the moon through a special telescope he built for the purpose.

Interactive Gallery

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. His *Discourse on Method* 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. At that point, he made his famous statement, "I think, therefore I am."

A Step-By-Step Process Over time, the scientific method evolved into a step-by-step process of discovery. Scientists collected and accurately measured 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.

For the first time, 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.

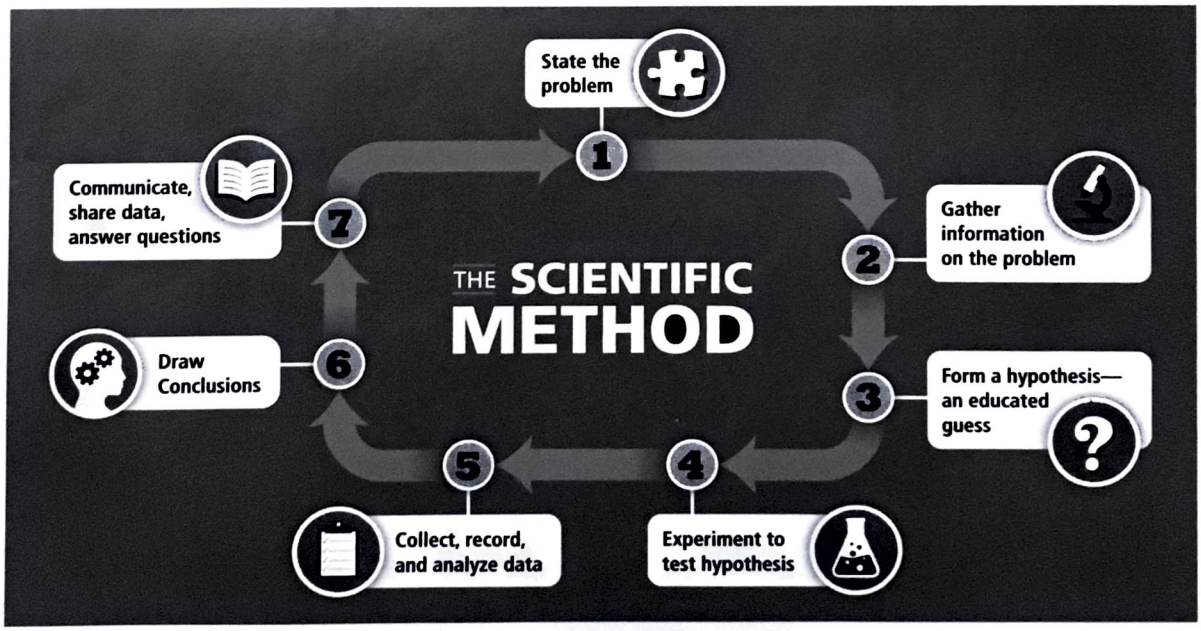
Thinkers like Bacon and Descartes helped bring the scientific method to the pursuit of all knowledge. Their pioneering approaches to thought opened the way to even more revolutionary ways of thinking in the 1700s.

EXPLAIN How did the ideas of Francis Bacon and René Descartes lead to a new scientific method?

Breakthroughs in Medicine and Chemistry

The 1500s and 1600s saw dramatic changes in many of the sciences, especially medicine and chemistry. Like Copernicus, Bacon, and Descartes, scientists rejected long-held assumptions. They relied on new technology, such as the microscope, and benefited from better communication, especially the availability of printed books.

Exploring Human Anatomy Medieval physicians relied on the works of the ancient Greek 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.



>> **Analyze Information** The scientific method, still used today, is based on careful observation and measurement of data. Why do you think it's critical to follow each step in sequence and to follow the same procedure for each step?

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's careful and clear drawings corrected errors inherited from ancient classical authorities.

About the same time, French physician Ambroise Paré (pa RAY) made many practical advances. He developed a new, more effective ointment for preventing infection and better ways to seal wounds during surgery. He introduced the use of artificial limbs and invented several scientific instruments.

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. Pioneering scientists like Harvey opened the way for further advances.

The Microscope Later in the 1600s, the Dutch inventor Anton van Leeuwenhoek (LAY wun hohk) perfected the single-lens microscope. Van Leeuwenhoek worked on grinding lenses as a hobby. He used them to examine tiny objects such as lice or the mouths of bees.

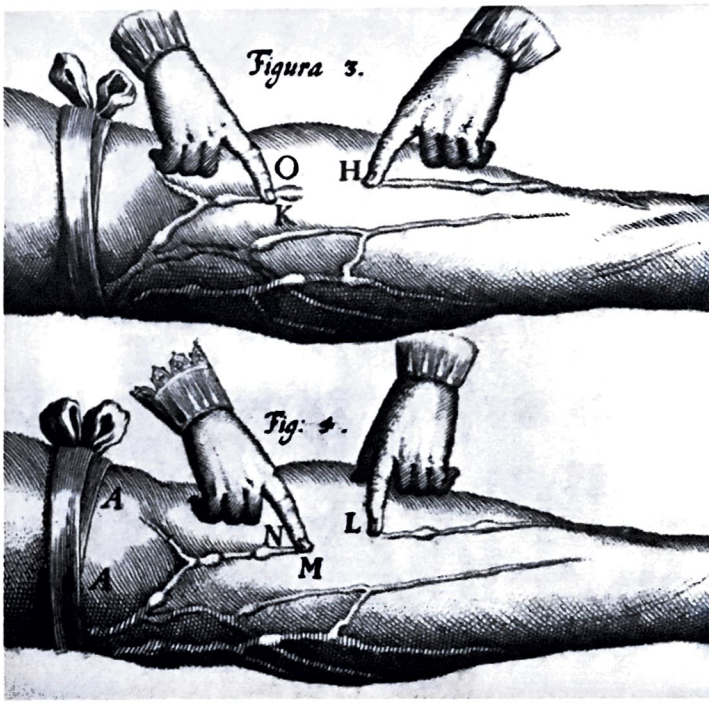
Peering through his microscope at drops of water, he was surprised to see tiny organisms, which he called "very little animalcules." Van Leeuwenhoek thus became the first human to see cells and microorganisms such as bacteria. For this work, he is often called the founder of microbiology. Over time, the microscope would lead to still more startling discoveries.

The New Science of Chemistry The branch of science today called chemistry was known as alchemy in medieval times. Alchemists believed that one substance could be transformed into another substance and tried to turn ordinary metals into gold. During the Scientific Revolution, chemistry slowly freed itself from the magical notions of alchemy. Still, scientists benefited from some of the alchemists' practical knowledge, such as the manipulation of metals and acids.

In the 1600s, English chemist **Robert Boyle** explained that all matter was 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.

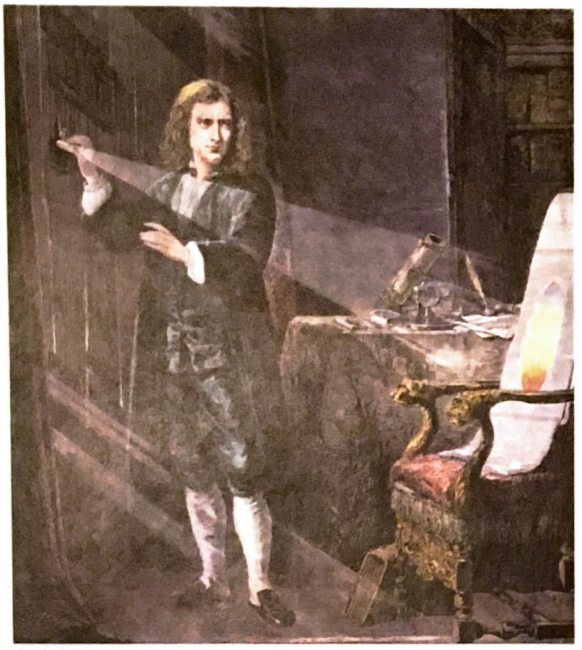
Isaac Newton Links the Sciences As a student at Cambridge University in England, **Isaac Newton** devoured the works of the leading scientists of his day. By age 24, he had formed a brilliant theory to explain why the planets moved as they did. According

>> English surgeon John Banister dissects a corpse to teach students about human anatomy. New approaches to scientific investigation helped to change how physicians learned about the human body.



>> An illustration from the circulatory system from William Harvey's book, *On the Motions of the Heart and Blood*. Harvey revolutionized medicine by suggesting that blood circulates continuously throughout the body.

Interactive Gallery



>> Isaac Newton performs an experiment to analyze how light is made up of a spectrum of different colors.

to one story, Newton saw an apple fall from a tree. He wondered whether the force that pulled that apple to Earth also controlled the movements of the planets.

Over the next 20 years, Newton perfected his theory. To do so, he developed the basis for **calculus**, a branch of mathematics. 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 *Mathematical Principles of Natural Philosophy*, 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 people, Newton's work seemed to link the sciences of physics and astronomy with mathematics, just as gravity bound the universe together.

For more than 200 years Newton's laws held fast, until the early 1900s, when a revolution in physics once more transformed the way people saw the universe. Still, Newton's work, ranging from the laws of motion and gravity to mathematics, makes him one of the most influential scientists of all time.

? **EXPLAIN** How did Boyle's research transform chemistry into a real science?

ASSESSMENT

1. **Recognize Ideologies** How did the theories of Copernicus and Galileo change the way people understood the universe?
2. **Make Generalizations** In what ways did the scientific method differ from earlier approaches to learning?
3. **Identify Cause and Effect** What impact did Reformation ideas have on medicine?
4. **Synthesize** How did Newton use the ideas of Plato?
5. **Infer** How did the Reformation help spur the Scientific Revolution?