The Scientific Revolution

A Unit of Study for Grades 7–12

Carole Collier Frick

WORLD HISTORY

Era Six: The Emergence of the First Global Age, 1450–1770

NATIONAL CENTER FOR HISTORY IN THE SCHOOLS
University of California, Los Angeles

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Reprint Edition, March, 1999

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Acknowledgments

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At the time the original unit was printed, Linda Symcox wasProject Director of the National Center for History in the Schools (NCHS). Important contributions to the first printing included: Geoffrey Symcox read and edited the manuscript, Margaret McMillen copy-edited, Leticia Zermeno provided copyright-research activities, and Alexey Root for proofread. Brenda Thomas created the first desktop layouts and unit designs, and brought the publication to final completion.

National Center for History in the Schools' (NCHS) Director, Gary B. Nash and NCHS Assoicate Director David Vigilante provided edits and revision suggestions for this reprint edition. Marian McKenna Olivas was the layout and photo editor.

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Introduction

Approach and Rationale

The Scientific Revolution is one of over 60 National Center for History in the Schools teaching units published by the National Center for History for the Schools that are the fruits of collaborations between history professors and experienced teachers of World History. They represent specific "dramatic episodes" in history from which you and your students can pause to delve into the deeper meanings of these selected landmark events and explore their wider context in the great historical narrative. By studying a crucial turning-point in history the student becomes aware that choices had to be made by real human beings, that those decisions were the result of specific factors, and that they set in motion a series of historical consequences. We have selected dramatic episodes that bring alive that decision-making process. We hope that through this approach, your students will realize that history is an ongoing, open-ended process, and that the decisions they make today create the conditions of tomorrow's history.

Our teaching units are based on primary sources, taken from government documents, artifacts, magazines, newspapers, films, private correspondence, literature, contemporary photographs, and paintings from the period under study. What we hope you achieve using primary source documents in these lessons is to have your students connect more intimately with the past. In this way we hope to recreate for your students a sense of "being there," a sense of seeing history through the eyes of the very people who were making decisions. This will help your students develop historical empathy, to realize that history is not an impersonal process divorced from real people like themselves. At the same time, by analyzing primary sources, students will actually practice the historian's craft, discovering for themselves how to analyze evidence, establish a valid interpretation and construct a coherent narrative in which all the relevant factors play a part.

In our approach, the continuing narrative provides the context in which the dramatic moment is situated. By studying a crucial turning-point in history, the student becomes aware that choices had to be made by real human beings, that those decisions were the result of specific factors, and that they set in motion a series of historical consequences. We have selected dramatic moments that best bring alive that decision-making process. We hope that through this approach, your students will realize that history is an ongoing, open-ended process, and that the decisions they make today create the conditions of tomorrow's history.

Content and Organization

Within this unit, you will find: 1) Unit Objectives, 2) Correlation to the National History Standards, 3) Teacher Background Materials, 4) Lesson Plans, and 5) Student Resources. This unit, as we have said above, focuses on certain key moments in time and should be used as a supplement to your customary course materials. Although these lessons are recommended for grades 7–10, they can be adapted for other grade levels. The teacher background section should provide you with a good overview of the entire unit and with the historical information and context necessary to link the specific "dramatic moment" to the larger historical narrative. You may consult it for your own use, and you may choose to share it with students if they are of a sufficient grade level to understand the materials.

The Lesson Plans include a variety of ideas and approaches for the teacher which can be elaborated upon or cut as you see the need. These lesson plans contain student resources which accompany each lesson. The resources consist of primary source documents, any handouts or student background materials, and a bibliography.

In our series of teaching units, each collection can be taught in several ways. You can teach all of the lessons offered on any given topic, or you can select and adapt the ones that best support your particular course needs. We have not attempted to be comprehensive or prescriptive in our offerings, but rather to give you an array of enticing possibilities for in-depth study, at varying grade levels. We hope that you will find the lesson plans exciting and stimulating for your classes. We also hope that your students will never again see history as a boring sweep of inevitable facts and meaningless dates but rather as an endless treasure of real life stories and an exercise in analysis and reconstruction.

Teacher's Background

I. Unit Overview

The purpose of this Unit is for the student to explore the advances in scientific knowledge made in Europe in the mid-sixteenth to mid-seventeenth centuries. These advances, beginning with Copernicus, radically changed man's basic notions of the very structure of the universe, in which he was no longer the center. The Copernican vision replaced the Ptolemaic notion of an earth-centered universe with a new "solar system" which had the sun at its center. As this idea gained ground, its supporters like Galileo developed a new method to prove its validity which rejected all unsubstantiated authority, and instead used careful observation and mathematical reasoning. With the help of this method it now seemed possible to understand the very laws which governed the physical world.

The unit, based on primary sources, introduces students to the contributions of the key scientists of the Scientific Revolution and to their basic discoveries and inventions, using illustrations and short excerpts from their works. **Lesson One** compares the ancient earth-centered universe of Ptolemy with the new sun-centered solar system of Copernicus. **Lesson Two** deals with the invention of the telescope, and how Galileo's telescopic observations not only verified the Copernican theory, but also had grave social consequences for the scientist. **Lesson Three** focuses on the development of the Scientific Method by Francis Bacon and René Descartes. Students will see how empirical investigation became widespread, and how the dissemination of information was aided by the establishment of the English Royal Society in London and the French Academy of Sciences. **Lesson Four** expands the scientific domain from discoveries in astronomy and the social realm, to the world of the microscope, and its expansion of human consciousness to the miniature world previously unavailable.

The changes wrought by the Scientific Revolution of the mid-sixteenth and seventeenth centuries will introduce students to the historical beginnings of our modern scientific age. During this time, "natural philosophy" became "science". Fundamental issues such as the difference between belief and mathematical proof will be discussed, as well as the social consequences of attempting to replace a long-established authority with a new one. This unit also shows the practical application of these new ideas, with the inventions which followed naturally from their use. By following the development of scientific advances, students will be able to trace the dissemination of these ideas, seeing how governments aided research and facilitated communication between scientists by establishing and funding scientific organizations. This unit is crucial for students to be able to understand how reliance on long-established but unsubstantiated authority gave way to the scientific method.

Based on empirical evidence through observation and experimentation, the scientific method was used to predict the outcome of theoretical work, and achieved practical success in medicine and technology. As Galileo scholar Stillman Drake has written, "The truly influential and pervasive aspects of modern science are not its facts at all, but rather its method of inquiry and its criterion of truth."[1] This unit provides a critical historical link between the age of faith and the age of reason for students. This new, rational approach to learning had far-reaching consequences for society and religion, and created the basis for our modern world.

[1] Stillman Drake, *Discoveries and Opinions of Galileo* (New York: Doubleday, Anchor Books, 1957), p. 3.

II. Unit Context

This unit should come after covering the Protestant Reformation and the fragmenting of a Europe unified by the Catholic Church. The students should also have covered the changes introduced by the humanistic thought of the Renaissance, which would have included a discussion of the re-discovery of the Greek and Latin thinkers of antiquity. This unit on the Scientific Revolution would be followed logically by a lesson on the Age of the Enlightenment, coupled with the development of the Absolutist State.

III. Correlation to National Standards for World History

IV. Unit Objectives

1. To understand the radical difference between the notion of a sun-centered and an earth-centered universe, and the far-reaching implications of such a fundamental shift in thinking.

2. To comprehend the difference between gaining knowledge based on accepted authority and gaining knowledge through rational thinking and empirical proof.

3. To discern the social consequences of challenging existing doctrines with new ideas.

4. To learn about the Scientific Method and how to apply it to problem-solving.

5. To see the role envisioned for science in helping society to advance and make progress.

6. To understand the impact of the scientific approach upon European society and culture.

V. Introduction to the Scientific Revolution

The startling mathematical calculations first published in 1543 by Nicolaus Copernicus in his *Concerning the Revolutions of the Celestial Spheres*, showed the earth as a moving planet. This challenged the long-accepted belief of a motionless earth at the center of the universe, which had been described by the astronomer Ptolemy nearly 1400 years earlier at Alexandria, Egypt. Copernicus went on to posit the revolutionary notion that the sun, rather than the earth, was at the center of a "solar system," around which all spheres revolve. A debate began between the supporters of the traditional, Aristotelian-Ptolemaic world-view, and the proponents of the Copernican system.

Galileo then made telescopic discoveries, further validating this Copernican vision of the universe, which he discussed both in his *Starry Messenger* of 1610, and in his masterwork, *Dialogue on the Two Great World Systems* of 1632. Meanwhile, Johannes Kepler developed his three laws of planetary motion in 1609 and 1619, which he based on the findings of his mentor, the Danish astronomer Tycho Brahe. Kepler proved mathematically that Copernicus' findings were true, and was the first astronomer to say so openly. Later, the foundation of the principle of gravitation was developed by Sir Isaac Newton in his comprehensive laws of physics, which ordered the physical world into a cohesive and orderly system.

The reliance on strict observation and mathematical proofs to check the validity of a hypothesis was a fundamentally new idea which replaced the philosophical ideas of Aristotle, upon which the study of natural science had been based. These scientific advances, based on the process of observation, generalization and then experimentation, whose outcome could be predicted, gave birth to many basic discoveries and technological inventions which aided and ultimately changed methods of investigation.

To allow the precise observation and measurement demanded by the new scientific method, scientists and inventors came up with many of the basic tools which were necessary for research. These included the microscope, in principle first discovered in 1590 by a Dutch spectacle maker named Zacharias Janssen, and later, the science of microbiology actually developed by Anton Van Leeuwenhoek. In 1593, the thermometer was invented by Galileo, and then improved upon by Gabriel Fahrenheit in the mid-1600s. The telescope, first devised in 1608 by a Dutch optician named Hans Lippershey, was then built a year later by Galileo. With it he was able to see not only the craters on the moon, but also the rings of Saturn and four of the satellites of Jupiter. As he wrote in his *Starry Messenger* in 1610, this view of the imperfection on the surface of the moon shattered all medieval notions of the perfection of the celestial orbs, and threatened the authority of the Church, which then subjected Galileo to the threat of excommunication and virtual house arrest for the rest of his life.

Another instrument, the barometer, was invented in 1643 by Evangelista Torricelli, who had been a pupil of Galileo. The barometer measured the pressure of air, and its accuracy was later proven by Blaise Pascal. The fifth important advance came with the invention of the air pump, which was a basic device for moving liquids and gases. All of these inventions were critical for aiding scientific research.

Equally important in propelling scientific research forward were the men who believed in this new method of investigation, and spread their views in their writing. One of the most important advocates of science was a contemporary of Galileo, the English aristocrat Francis Bacon, (1561–1626) who became Chancellor of England in 1618. In his *Instauratio Magna* (Great Beginning) of 1605–1620, he wrote of the limitations of the existing systems of understanding in their inability to predict. He called for a new direction in learning, using experimentation as a way of investigation. In his *New Atlantis*, published in 1627, Bacon even envisioned a utopian society where science would become the savior of the human race. Later, his vision of scientific organization was made real by the establishment of the English Royal Society in London in 1660, followed by the French Academy of Sciences in 1666.

The writings of the French mathematician René Descartes (1596–1650), who began his *Discourse on Method* (1637) with the statement "I think, therefore I am *Cogito ergo sum*)," also stimulated interest in this new, optimistic notion of man's rational abilities. Buoyed with enthusiasm for predictability in scientific research, European governments subsidized more extensive investigation in the hopes of discoveries and inventions which would be of practical application in the areas of medicine, technology, and economic prosperity.

The culminating genius of the Scientific Revolution was the English physicist, Sir Isaac Newton (1642–1727). In 1687, after years of calculations built in part on the work of Galileo and Kepler in planetary and terrestrial motion, Newton published his *Mathematical Principles of Natural Philosophy*, or *Principia*, as it is often known. In this work of creative synthesis, Newton found a way to bring Kepler and Galileo together, showing that the same laws governed both the terrestrial and celestial realms. He gave mathematical proofs that all motion could be calculated and measured, and represented by a universal mathematical formula. The force which held the universe together was his "universal gravitation," a concept which remained unchallenged for two hundred years. It has been for this century to push past the universality of this concept, discovering its limits in subatomic structures and in the vast outer reaches of the physical universe.

You may wish to introduce the study of the Scientific Revolution by providing students with the names of individuals who are mentioned in this unit, a chronological chart of the Scientific Revolution, and a map locating the place of birth of each of these scientists (**Student Handouts 1-3**, pp. 13–15). As students investigate the lives and work of prominent scientists of the period you may also have them locate on the map where they made their important scientific discoveries or published their findings.

VI. Lesson Plans

1. Ptolemy and Copernicus

2. Galileo and His Telescope

3. Bacon and Descartes

4. The Development of the Microscope

Dramatic Moment
Galileo Discovers Craters on Moon

In the year of 1609, Galileo Galilei, an Italian university professor teaching in Padua, Italy, heard about an intriguing new device called a spyglass, which had been made by a Dutch optician. Adapting the Dutch invention in his own studio, Galileo built himself a primitive spyglass, or telescope, which had the power to bring objects thirty-three times closer than our natural vision.[1] He decided to use this new device to observe the heavens.

Night after night, Galileo sat looking into the dark sky, with his new telescope trained on the heavens, recording and sketching what he saw. In 1610, he described his observations in the *Starry Messenger*, dedicated to his patron, Cosimo II de Medici, the Fourth Grand Duke of Tuscany. After looking through his spyglass at the moon, he wrote:

> Great indeed are the things which in this brief treatise I propose for observation and consideration by all students of nature. I say great, because of the excellence of the subject itself, the entirely unexpected and novel character of these things, and finally because of the instrument by means of which they have been revealed to our senses. Surely it is a great thing to increase the numerous host of fixed stars previously visible to the unaided vision, adding countless more which have never before been seen, exposing these plainly to the eye, in numbers ten times exceeding the old and familiar stars.
>
> It is a very beautiful thing, and most gratifying to the sight, to behold the body of the moon . . . so that its diameter appears almost thirty times larger [than] when viewed with the naked eye.

He also wrote casually, courting danger,

> . . . one may learn with all the certainty of sense evidence that the moon is not robed in a smooth and

> polished surface but is in fact rough and uneven, covered everywhere, just like the earth's surface, with huge prominences, deep valleys and chasms."[3]

The radical notion that any "perfect" heavenly body had anything in common with the "imperfect" realm of the earth, was a potentially dangerous opinion. The Roman Catholic Church, a powerful political force in Europe at that time laid down that the heavenly bodies, because of their nearness to God, must be more perfect than the Earth. Any differing ideas were considered unchristian, or heretical, and were severely punished. The Church had suffered gravely from the dissenting views of Luther and the other Reformers, and did not intend to allow further attacks on its dogma.

But Galileo did not stop with his description of the moon. In the same *Starry Messenger*, he decsribed other discoveries which suggested that Copernicus had been right when he wrote that the earth was not the motionless center of the universe, but only a small planet, among several others, moving around the sun. We were, in fact, simply part of a "solar" system. This revolutionary idea that the earth moved was reported to the Church authorities, who began to investigate this man and his revolutionary findings.

Using his telescope, Galileo based his findings on direct empirical, or sensory observation, and discarded the old systems of thought based on the accepted authorities of the Bible, and the ancient philosphers Aristotle and Ptolemy, who had been absorbed into Catholic dogma. He outspokenly defended his way of doing things in a letter to the Grand Duchess Christina, writing,

> . . . I think that in discussions of physical problems we ought to begin not from the authority of scriptural passages, but from sense-experiences and necessary demonstrations; for the holy Bible and the phenomena of nature proceed alike from the divine Word. . . . For that reason it appears that nothing physical

> which sense-experience sets before our eyes . . . ought to be called in question (much less condemned) upon the testimony of biblical passages which may have some different meaning beneath their words."[4]

With this strongly independent statement, Galileo stirred up a storm of outrage from the Church starting a chain of events which would ultimately lead to, in 1632, his prosecution for heresy by the Papal Inquisition. Religious officials demanded that he abandon his views on the nature of the celestial realm. In 1632, Galileo was called to appear before the Inquisition to defend himself against charges of heresy against the teachings of the Roman Catholic Church, . . .

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1. The term "telescope" was not coined until 1611, when a new Latin word, "telescopium," was created to give a name to this invention.

2. Galileo Galilei, *Starry Messenger*, in *Discoveries and Opinions of Galileo*, translated and notes by Stillman Drake, New York: Anchor Book Doubleday & Co., 1957, pp. 27-28.

3. *Ibid*., p. 28.

4. Galileo Galilei, *Letter to the Grand Duchess Christina, ibid*., pp. 182-83.

Lesson One
Ptolemy and Copernicus

A. Objectives

1. To understand the ancient Ptolemaic view of the universe, with the earth at the center.

2. To see how different Copernicus' "solar system" is from Ptolemy's.

3. To draw conclusions about these two models of the universe.

B. Historical Background Notes

In 1543, the Polish priest and astronomer Nicholas Copernicus (1473-1543) posthumously published his book *Concerning the Revolutions of Celestial Spheres*, in which he presented a revolutionary new model of the very structure of the universe, with the sun at its center. His ideas, based on mathematical calculations, rejected the ancient view of Ptolemy, which had placed the earth at the center.

Ptolemy's model, dating from the Hellenistic period at Alexandria, Egypt in ca. 150 A.D., had been the view which had been taught by religious leaders. Copernicus' new model threatened the established doctrine of these Church writers, who understood the Bible as supporting the Ptolemaic notion (Joshua commanded the sun to stand still: i.e. it had to be in motion around the Earth). Leaders from both the Roman Catholic and the Protestant church condemned this new idea as false. It would be up to Kepler and Galileo to prove Copernicus correct by using the new invention of the telescope and logical analysis of empirical evidence.

C. Lesson Activities

Activity One

1. Introduce the lesson by leading a discussion on basic physical assumptions; in other words what things class members just take for granted about reality. (For example, that the earth is round; that the sun will come up in the morning; that if they roll a ball really hard, it will continue rolling until something stops it, etc.).

2. Divide the Class into Group A and Group B, giving Group A **Illustration 1**, *Ptolemy's Classical Model of the Universe*, (dating from 150 A.D.) and Group B, **Illustration 2**, *Copernicus' New Model*, (first introduced in 1543).

3. Have each group "read" their assigned model and appoint a notetaker to make a list of what they see in the drawing.

4. Bring the class back together and have group leaders present each document, listing the main points on the board, as a basis for class discussion on the differences in the two models.

Discussion Questions

a. What do these drawings represent?

b. What is the most important difference between the two?

c. What does Ptolemy's model contain that is absent from Copernicus'?

d. How might a change this drastic make people feel about their world, and their place in it?

e. How would your ideas have to change if you believed in Copernicus' idea?

f. How do you think that Copernicus could have come up with such a different model of the Universe?

g. How do you think the people of the sixteenth century would react to his idea of the universe?

E. Vocabulary

geocentric   heliocentric

F. Pronunciation Key

Ptolemy (TAHL-EH-ME)   Copernicus (KO-PAIR-NEE-KUS)

G. Evaluating the Lesson

Informal evaluation of group lists and class discussion.

Copernicus honored on an Hungarian stamp.

Men of the Scientific Revolution

Nicolas Copernicus (1473–1543)

Tycho Brahe (1546–1601)

Francis Bacon (1561–1626)

Galileo Galilei (1564–1642)

Hans Lippershey (ca. 1570–ca. 1619)

Johannes Kepler (1571–1630)

Francesco Stelluti (1577–ca. 1652)

Zacharias Jansen (1580–1638)

René Descartes (1596–1650)

Evangelista Torricelli (1608–1647)

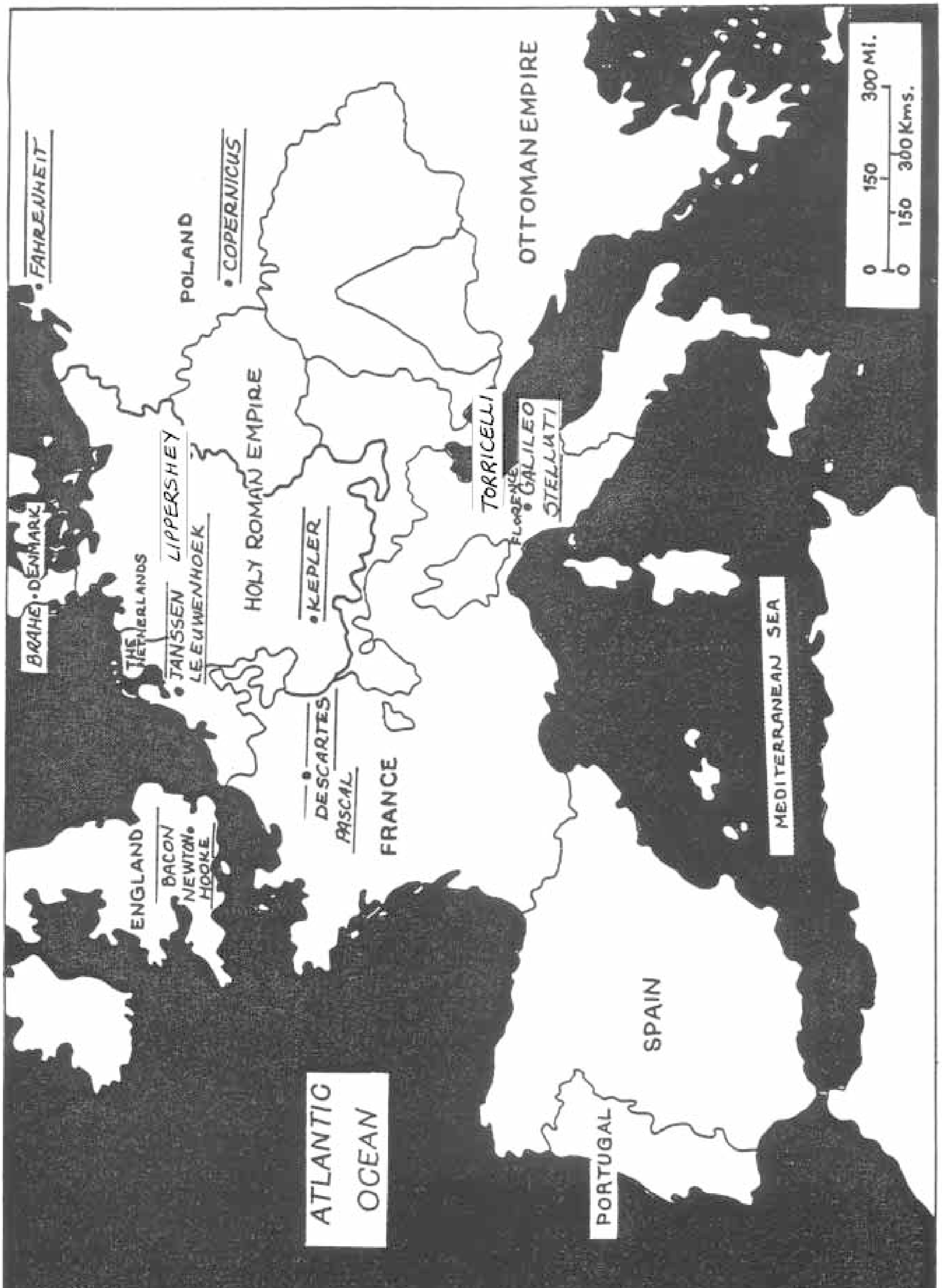
Blaise Pascal (1623–1662)

Anton Van Leeuwenhoek (1632–1723)

Robert Hooke (1635–1703)

Isaac Newton (1642–1727)

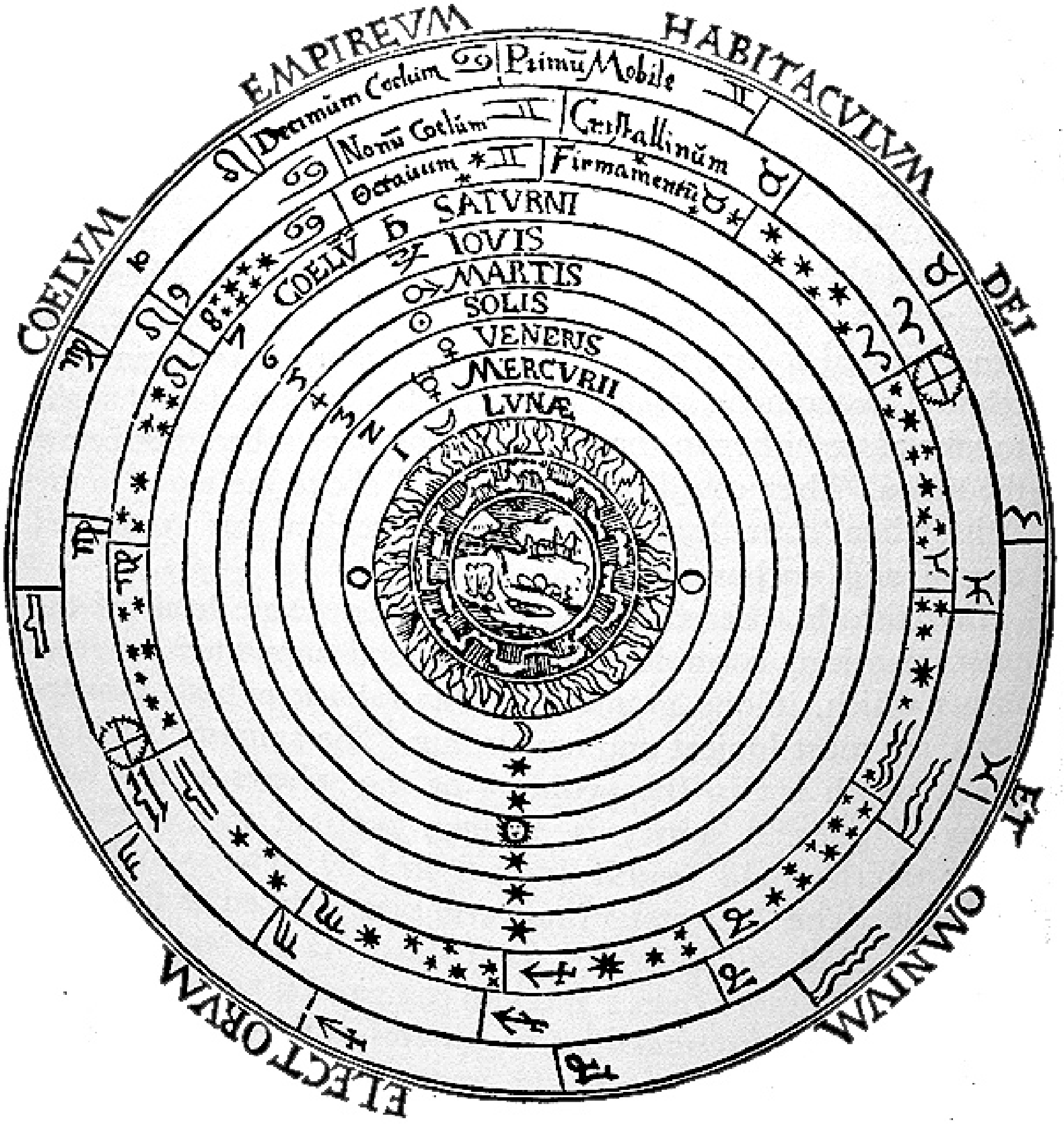
Gabriel Fahrenheit (1686–1736)


ATLANTIC OCEAN
ENGLAND
BACON
NEWTON
HOOKE
FRANCE
DESCARTES
PASCAL
SPAIN
PORTUGAL
MEDITERRANEAN SEA
THE NETHERLANDS
JANSSEN
LEEUWENHOEK
LIPPERSHEY
BRAHE
DENMARK
HOLY ROMAN EMPIRE
KEPLER
POLAND
COPERNICUS
FAHRENHEIT
TORRICELLI
FLORENCE
GALILEO
STELLUTI
OTTOMAN EMPIRE
0 150 300 MI.
0 150 300 Kms.

SCIENTIFIC REVOLUTION: A CHRONOLOGICAL TABLE

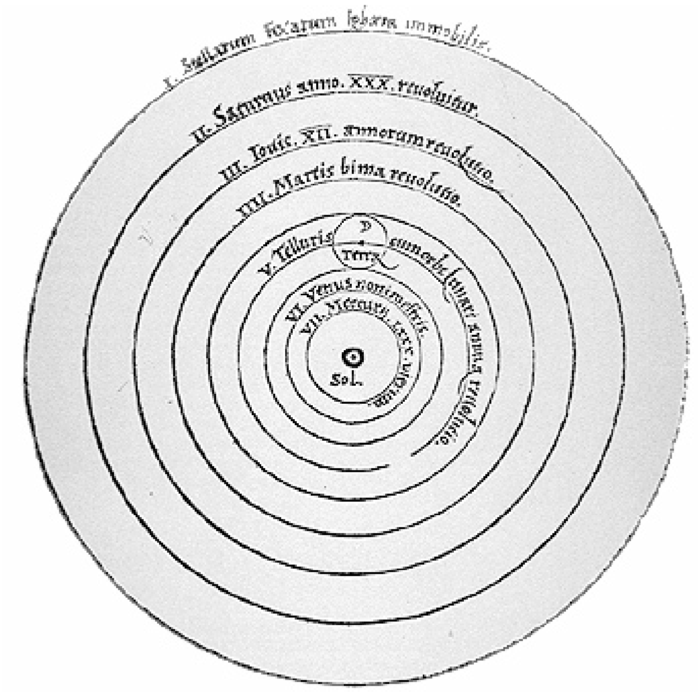
1543	Copernicus writes *On the Revolutions of the Heavenly Spheres*
1590	Zacharias Janssen invents **microscope**
1593	Galileo invents **thermometer**
1605–20	Francis Bacon writes *Instauratio Magna* (Great Beginning)
1608	Hans Lippershey invents **telescope**
1609–19	Johannes Kepler publishes *Three Laws of Planetary Motion*
1610	Galileo writes *Starry Messenger*
1613	Galileo writes *History and Demonstration Concerning Sun Spots*
1625	Francesco Stelluti publishes *Microscopic Studies of Honeybee*
1627	Bacon writes *New Atlantis*
1632	Galileo writes masterwork, *Dialogue on the Two Great World Systems*
1633	Trial of Galileo
1637	René Descartes writes *Discourse on Method*
1643	Evangelista Torricelli (student of Galileo's) invents **barometer**
1660	English Royal Society established
1665	Robert Hooke publishes *Micrographia*
1666	French Academy of Sciences established
1687	Sir Isaac Newton publishes *Principia*

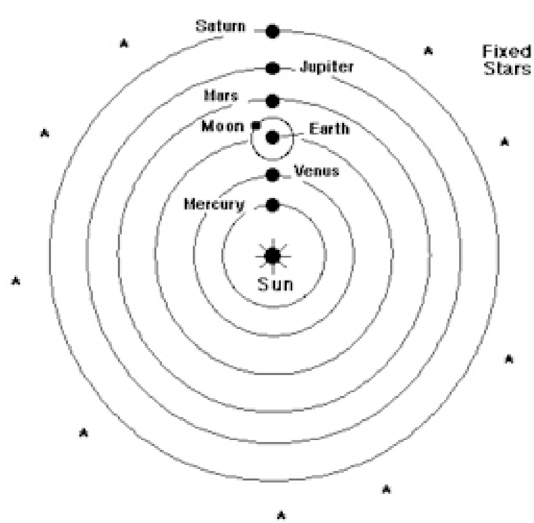
PTOLEMY'S CLASSICAL MODEL OF THE UNIVERSE CA. 150 A.D.



Albert Van Helden and Elizabeth Burr, *Galileo Project*. Houston, TX: Rice University, 1996. http://es.rice.edu/ES/humsoc/Galileo/

Copernican Model of the Universe ca. 1543 A.D.





Albert Van Helden and Elizabeth Burr, *Galileo Project*. Houston, TX: Rice University, 1996. http://es.rice.edu/ES/humsoc/Galileo/

Lesson Two
Galileo and his Telescope

A. Objectives

1. To understand the importance of the development of the telescope in Galileo's direct observation of heavenly bodies.

2. To comprehend the difference between knowledge based on accepted authority and knowledge gained by individual, rational thinking and empirical proof.

3. To see the value of developing new ideas for the advancement of general knowledge.

4. To also discern the social consequences of challenging an existing authority with new ideas.

B. Historical Background

In 1608 Hans Lippershey, a Dutch optician, is believed to have made the first refracting telescope (with lenses, rather than mirrors, like our large modern telescopes) which he called a spyglass. Lippershey was unable to obtain a patent on his invention as is done today. Thus, a year later, in 1609, the Italian astronomer and mathematician Galileo Galilei (1564–1642), heard about Lippershey's invention, and built his own improved model. Galileo, who was a professor of mathematics at the University of Padua, used his own home-made telescope to make some startling new discoveries. He proved, along the way, that the heliocentric theory of Copernicus was correct.

Galileo was the first person to see and write about the imperfections of celestial bodies. He observed the mountains and craters of the moon, the rings of Saturn, and the sunspots on the sun. In 1613, he also discovered four of the moons of Jupiter, which was the discovery that gave him hard evidence to prove Copernicus' heliocentric theory that all heavenly bodies do not revolve around the Earth. He had seen, through his telescope, objects orbiting another planet!

Galileo published his startling findings in many letters and books, including his *Starry Messenger* of 1610 (in which he wrote about the Earth's moon and the moons of Jupiter and his *History and Evidence about Sunspots*, written in 1613. He appealed to his readers to validate for themselves his findings by observing the very things he himself had seen, by using the device of a telescope. His appeal was to the knowledge available by the empirical evidence through sensory perception and logical analysis, rather than the reliance on accepted authority and canonical texts.

In 1632, Galileo's masterwork, the *Dialogue on the Two Great World Systems*, was published in The Netherlands, a more tolerant and receptive country than his native Italy. This work discussed the Ptolemic and Copernican systems and Galileo favored the latter. He wrote the book in Italian, not in the Latin traditionally used for scholarly works, so that it would be accessible to more readers.

Predictably, the Roman Catholic Church, whose authority on the heavens he had challenged, responded by called upon Galileo to make a complete retraction. Church doctrine had taught the perfection of the celestial spheres, in opposition to the imperfection of the earthly realm. Galileo's findings showed clearly that the celestial realm was no different than the earth in its imperfections. He also showed that the earth was not the center of the universe, but only a small planet in a greater solar system. His empirical proof of such a basic reorientation of the universe upset all Biblical and ancient models which existed at that time.

In 1633, he was brought before the Inquisition of the Roman Catholic Church, and after a lengthy trial, was forced to sign a statement saying that he did not really believe his findings, especially that the earth moved around the sun. Under threat of excommunication from the Church, Galileo retracted his beliefs in front of the Pope at the Vatican, but the story goes that as he was led away, he muttered, "Eppur si muove," or "but it moves." In spite of the fact that the Pope was a personal friend of his, Galileo's discoveries were still deemed too dangerous to be disseminated. He was arrested and then put under house arrest for the rest of his life in his villa outside Florence. Galileo died there, imprisioned at his own home, nine years later. But he was still able to continue his reasearch and writing.

In spite of his banishment from the public to the private sphere, and the fact that the Church also put all of his works on their Index of Forbidden Books, (where they remained for the next 200 years), Galileo's works reached a large audience, and influenced scientists and philosophers the world over. For example, by 1614, only five years after the *Starry Messenger* first appeared, a Jesuit missionary in Peking was publishing Galileo's findings in Chinese. His ground-breaking work with the telescope was augmented by many other pioneering scientists and astronomers of the 16th- and 17th-century Scientific Revolution, and his discoveries revolutionized the field of astronomy.

C. Lesson Activities

1. With an overhead projector, project **Illustration 3**, a portrait of Galileo, for the class. Ask students to describe in detail what they see; how Galileo's publisher wished to present him. (Optimistic portrait of a successful Galileo himself, smiling; at top, two confident angels, one looking through a spyglass, the other making measurements with an astrolabe and recording results; above Galileo's head, another angelic creature wearing a victorious laurel wreath; at bottom, a goat-headed devil with four snakes [ignorance being vanquished?])

2. Have two students read the **Dramatic Moment** to the class, one student being the narrator and one being Galileo.

3. Divide the class into three groups.

   a. Pass out **Documents A, B**, and **C-1** to the class. All of these primary sources are from Galileo's writings, and each one describes a different astronomical discovery. Each document is illustrated to facilitate students' understanding.

   b. Each group will discuss their document and illustration among themselves, and then appoint a leader to report to the class.

   c. Bringing the class back together, group leaders will present each document, listing main points on the board, Guide the class in a discussion.

Discussion Questions

a. What are the differences between the documents? (Galileo has discovered completely new astronomical findings which contradict current beliefs about the cosmos).

b. What has Galileo discovered? (The nature of the Milky Way and "nebulous stars," moons of Jupiter, spots on the sun).

c. How would he have been able to discover this (through the use of the telescope)? Discuss what this means (by using empirical knowledge based on his own observation, then analyzing his findings through the use of rational logic, he has come to some startling new findings).

d. Where in these documents can you see evidence of Galileo's method of inquiry? (At various places in the **Dramatic Moment** and the documents).

e. How is this different from how men knew about the planets or "wandering stars," as Galileo called them, before? Where had men previously gone for information? (Authorities like the Bible, books by "natural philosophers" [antique word for "scientist"] of antiquity like Aristotle and Ptolemy.)

f. Who were the existing authorities? (The Churchmen who had studied the ancient philosophers and were experts in their knowledge.)

g. Why was the Church so weary of critics in that it felt the need to stifle Galileo? (The Church's experience of criticism by Luther and Reformers which had split the Church irrevocably. It feared that Galileo might turn out to be another Luther.)

h. What would be the consequences for society if men as a result now began to rely on their own rational powers, their own ability to think and figure things out, rather than just obeying the existing authority? (People would be more independent; less willing to accept traditional authority; would feel more capable of being able to figure things out on their own.)

4. Read the **Historical Background** to the class. This provides the ending to the **Dramatic Moment**; that is, what happened to Galileo because of his discoveries.

5. Relating the lesson to students' own lives, discuss the difference between accepting established authority, and thinking for oneself.

Discussion Questions

a. What are some new ideas people now accept as better which began as challenges to existing authority? (It's better not to use torture to exact a confession; people do not have the right to beat animals even if they "own" them; women should have equal rights in a society; people should carpool instead of driving their own car to reduce pollution; society should provide facilities for the handicapped so they can function more independently; nations should discuss differences rationally rather than fighting wars over them; national concerns should give way to international priorities.)

b. What would happen if people never challenged the currently accepted beliefs or authorities? (There would be no progress, things would never change, mankind would not learn anything.)

c. In what ways does our society in the United States allow for people to express their beliefs and initiate change; to challenge existing authority? (Through political involvement, through freedom of speech and the media; through the national right to education.)

6. **Homework Assignment**

Have students write a one-page essay describing a way in which they would challenge an existing authority on an issue they believe should be questioned/changed. Students should think about this logically and seriously, and have a hands-on experience with the Scientific Method.

Note to the Teacher:

This homework assignment ties into **Lesson Three**, which introduces the work of Francis Bacon and René Descartes on the development of the scientific method of reasoning. The next lesson will provide them with the tools to redo this assignment, giving them specific directions for how to approach a problem logically. Students should be able to see an improvement in their ability to grapple with an idea in an organized manner after **Lesson Three**.

Ideas for topics:

a. Rules laid down by parents that are unreasonable.

b. School rules/classroom procedure that could be improved/ amended.

c. The way society handles an issue which should be changed.

d. Something about their life and/or environment that they do not agree with that should be dealt with differently.

e. Have them note the process by which they came to the conclusion that they did, and to justify their point of view, using their own rational abilities.

6. **Optional Activity**

This activity explores the history and principle of the refracting telescope, the type of "spyglass" that Galileo fashioned.

a. Have students read *Galileo's Telescope*, **Document C-2**.

b. Project **Illustration 4**, "Galileo's Own Telescope," with an overhead projector.

c. Have students research and draw simple diagrams of refracting telescopes.

D. Vocabulary

aether
concave
congeries
convex
ecliptic
elliptic
empirical knowledge
heresy
impugned
Inquisition
natural philosophy
nebula
nebulous
ocular
rational knowledge
refraction
wandering star

E. Pronunciation Key

aether (EE-THUR)
Galileo (GAL-EE-LAY-OH)

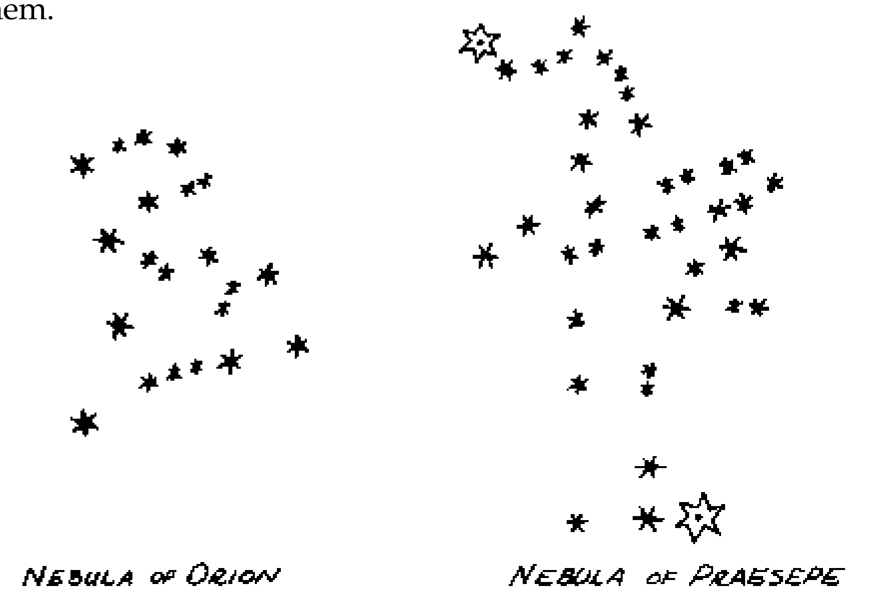
F. Evaluating the Lesson

Informal observation of discussion; evaluation of one-page essay on the use of independent rational thinking to arrive at new ideas/ideals.

Journal Entry from *Starry Messenger*

. . . I have observed the nature and the material of the Milky Way. With the aid of the telescope this has been scrutinized so directly and with such ocular (clarity of vision) certainty that all the disputes which have vexed philosophers through so many ages have been resolved, and we are at last freed from wordy debates about it. The galaxy is, in fact, nothing but a congeries of innumerable stars grouped together in clusters. Upon whatever part of it the telescope is directed, a vast crowd of stars is immediately presented to view. Many of them are rather large and quite bright, while the number of smaller ones is quite beyond calculation.

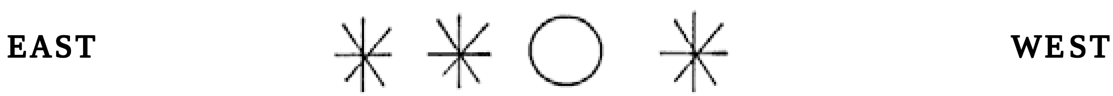
But it is not only in the Milky Way that whitish clouds are seen; several patches of similar aspect shine with faint light here and there throughout the aether, and if the telescope is turned upon any of these it confronts us with a tight mass of stars. And what is even more remarkable, the stars which have been called 'nebulous' by every astronomer up to this time turn out to be groups of very small stars arranged in a wonderful manner. Although each star separately escapes our sight on account of its smallness or the immense distance from us, the mingling of their rays gives rise to that gleam which was formerly believed to be some denser part of the aether that was capable of reflecting rays from stars or from the sun. I have observed some of these constellations and have decided to depict two of them.



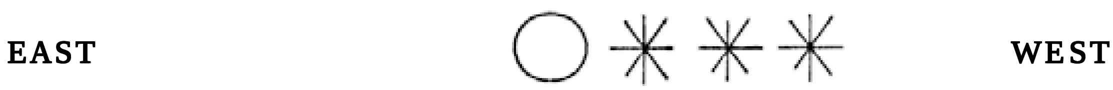
Sketch (after Galileo) of Nebula of Orion and Nebula of Praesepe from Galileo Galilei, *Starry Messenger* (1610), Figure Six.

JOURNAL ENTRY FROM *STARRY MESSENGER*

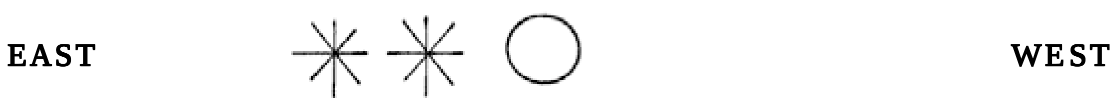
On the seventh day of January in this present year 1610, . . . when I was viewing the heavenly bodies with a spyglass, Jupiter presented itself to me; . . . I perceived . . . that beside the planet there were three starlets, small indeed, but very bright. . . . they aroused my curiosity somewhat by appearing to lie in an exact straight line parallel to the ecliptic, and by their being more splendid than others of their size. Their arrangement with respect to Jupiter and each other was the following:



that is, there were two stars on the eastern side and one to the west. . . . on January eighth . . . I found a very different arrangement. The three starlets were now all to the west of Jupiter. . . .

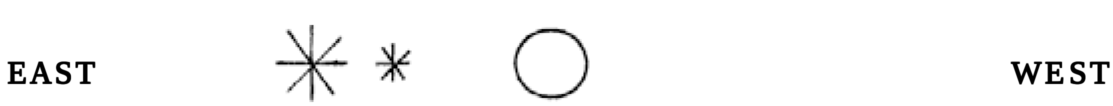


. . . I began to concern myself with the question how Jupiter could be east of all these stars when on the previous day it had been west of two of them. . . . On the tenth of January . . . the stars appeared in this position with respect to Jupiter:

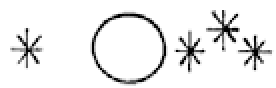


that is, there were but two of them, . . . the third (as I supposed) being hidden behind Jupiter. . . . on the 11th of January, I saw the following. . . .

There were two stars, . . . [one] star was nearly double the size of the former, whereas on the night before they had appeared approximately equal.



I had now decided beyond all question that there existed in the heavens three stars wandering about Jupiter. . . . Nor were there just three such stars: four wanderers complete their revolutions about Jupiter. . . . On the thirteenth of January four stars were seen by me for the first time, in this situation relative to Jupiter:

EAST  **WEST**

Three were westerly and one was to the east; they formed a straight line except that the middle western star departed slightly toward the north.

. . . Above all, since they sometimes follow and sometimes precede Jupiter by the same intervals, and they remain within very limited distances either to the east or west of Jupiter . . . no one can doubt that they complete their revolutions about Jupiter and. . . . also revolved in unequal circles . . .

Source: Galileo Galilei, *Starry Messenger*, translated by Stillman Drake, pp. 51–53, 56–57.

First Letter from Galileo Galilei in Reply to the Illustrious Mark Welser Concerning the Solar Spots

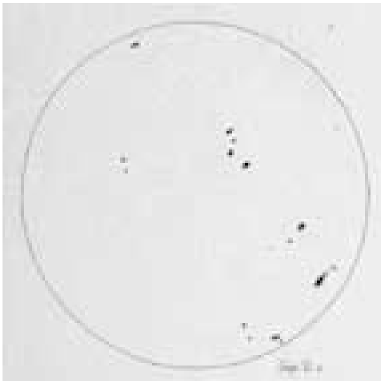
Most Worthy Sir:

Tardy in replying to the courteous letter Your Excellency wrote me three months ago, I have remained silent . . . until I might hope to give some satisfaction . . . about the solar spots. . . . As Your Excellency well knows, certain recent discoveries that depart from common and popular opinions have been noisily denied and impugned, obliging me to hide in silence every new idea of mine until I have more than proved it. Even the most trivial error is charged to me as a capital fault by the enemies of innovation. . . .

First of all, I have no doubt whatever that they [the sunspots] are real objects and not mere appearances or illusions of the eye. . . . I have observed them for about 18 months, having shown them to various friends of mine, . . . It is also true that the spots do not remain stationary upon the body of the sun, but appear to move in relation to it with regular motions. . . . The spots seen at sunset are observed to change place from one evening to the next. . . .

It proves nothing to say, . . . that it is unbelievable for dark spots to exist in the sun simply because the sun is a most lucid body. So long as men were in fact obliged to call the sun 'most pure and most lucid,' no shadows or impurities whatever had been perceived in it; but now that it shows itself to us as partly impure and spotty, why should we not call it 'spotted and not pure'?

Source: Galileo Galilei, *History and Evidence Concerning Sunspots and Their Phenomena* (1613), translated by Stillman Drake, pp. 89–92.



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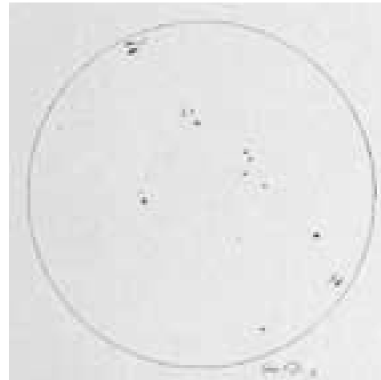

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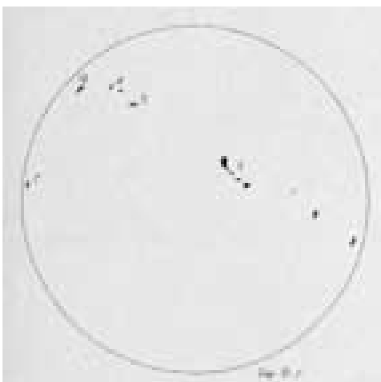

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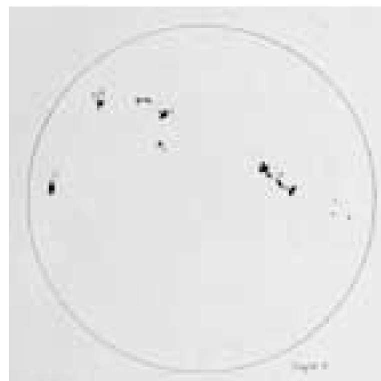

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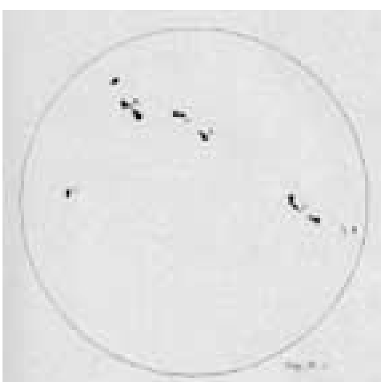

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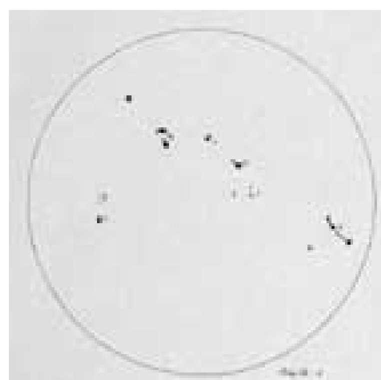


08 June 1613

Galileo's own sketches of sunspots. The entire series of sketches can be viewed online.
Albert Van Helden and Elizabeth Burr, *The Galileo Project* (Houston, TX: Rice University, 1995)
http://es.rice.edu/ES/humsoc/Galileo/Things/g_sunspots.html

Galileo

Courtesy of the William Andrews Clark Memorial Library

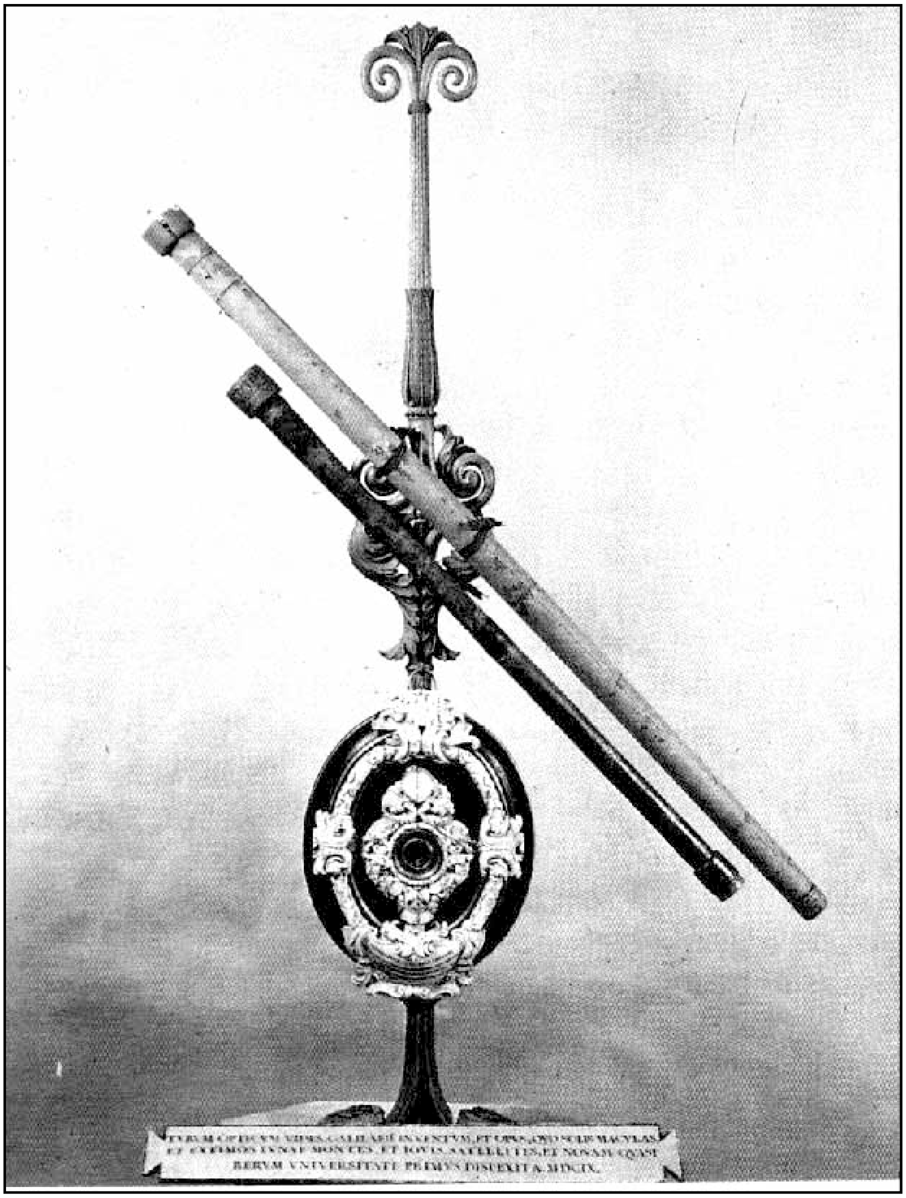
GALILEO'S TELESCOPE

Galileo himself needed to improve on the Dutch optician's invention of the spyglass, or telescope, to observe the heavens. He wrote to his patron, Cosimo II de' Medici, Grand Duke of Tuscany, describing how he first heard about this new invention, and built his own:

> About 10 months ago a report reached my ears that a certain Fleming [a man from what is now Holland], had constructed a spyglass by means of which visible objects, though very distant from the eye of the observer, were distinctly seen as if nearby. . . . A few days later the report was confirmed to me in a letter . . . which caused me to apply myself wholeheartedly to inquire into the means by which I might arrive at the invention of a similar instrument. This I did shortly afterwards, my basis being the theory of refraction. [Refractive telescopes use lenses, reflecting telescopes use curved mirrors to produce the same effect.]
>
> First I prepared a tube of lead, at the ends of which I fitted two glass lenses, both plane on one side while on the other side one was spherically convex [curved outward] and the other concave [curved inward]. Then placing my eye near the concave lens I perceived objects satisfactorily large and near, for they appeared three times closer and nine times larger than when seen with the naked eye alone.

Source: Galileo Galilei, *Starry Messenger*, translated by Stillman Drake, pp. 28-29.

Galileo's Own Telescope



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Lesson Three
Sir Frances Bacon and René Descartes

A. Objectives

1. To learn about the role envisioned for science as the new vehicle by which society will progress.

2. To learn about the scientific method, and apply it on their own to solve a problem.

B. Historical Background

One of the earliest thinkers to recognize that European society had reached its limits of intellectual growth under the doctrines of medieval thought was the Englishman Francis Bacon (1561–1626). In the medieval period, natural philosophers and thinkers had relied on canonical texts for truth. They saw the Bible and Aristotle as absolute authorities. In his great work, *Instauratio Magna* (Great Beginning), written between 1605–1620, Bacon eloquently described the conundrum facing a society which put its faith in ancient authoritative texts. It had left thinkers without a functional system of inquiry by which to progress. It was Bacon who called for a new science based upon empirical observation and experimentation, and constructed a program for how to do it. To enthusiastic Baconians, knowledge was power.

In his *New Atlantis* (1627), he wrote about a utopian society which had put science to work for the benefit of all. This vision of science as the savior of mankind perhaps helped to inspire the founding of the English Royal Society in 1660, and in 1666, the French Academy of Science. Both of these organizations provided not only forums for scientists to present their discoveries, but were also vehicles by which governments now could support and fund further scientific inquiry.

In France, the mathematician René Descartes (1596–1650) was another early visionary who wrote about the necessity of using a rigorously logical approach in scientific research. In his *Discourse on Method* (1637), he advanced the notion that to solve a problem logically, one must procede through an unchanging order of steps, which were:

1. To accept as true only those things about the problem of which one is absolutely certain. (This exercise prevented people from taking

things on faith from outside authorities, and instead, forced them to rely on their own minds).

2. To analyze one must take all doubts or unknown elements in the problem at hand, and list them from easiest to most difficult.

3. To work through the unknowns methodically from the simplest to the most complex.

4. To make the inquiry into the problem so complete that no point is left out or forgotten.

This deductive method became one of the earliest methods of scientific inquiry. By applying doubt to all of knowledge, the only thing Descartes was certain of was that he was, in fact, thinking. Out of this realization came his famous dictum, *Cogito ergo sum*, "I think, therefore I am." Descartes was very modern, because he based everything he knew on his own rational mind, taking no outside authorities. This approach assumed that human beings could open up the world to their own understanding, through the use of deductive logic.

C. Lesson Activities

Day One

1. Using an overhead projector, project **Illustration 5**, a portrait of Francis Bacon.

2. Read **Documents D1** to the class, an excerpt from Bacon's *Instauratio Magna* (Great Beginning) of 1620, and **D2**, the modern version, in which Bacon critiques the stagnation of learning, and notes the general lack of progress in making discoveries and inventions.

3. Conduct a class discussion about what Bacon is calling for and why.

Discussion Questions

a. What could have prompted Bacon to write about this? (concern for the lack of progress, stagnation of culture)

b. What is he worried about? (that society is not coming up with new inventions and/or ways of doing things)

c. What does the existing way of thinking lack? (a systematic way to approach all problems, great and small)

d. What does he want thinkers to do differently than they have been doing? (use their own senses and brains to figure things out, rather than relying on outside authority; use a logical approach to dealing with problems)

e. What are some authorities that people just took on faith to explain things? (the Bible, the Torah, Ptolemy, and Aristotle's texts)

4. Read the following, simplified introduction to Bacon's *New Atlantis* (1627) to the class, to prepare them for the next cooperative activity:

> Voyaging from Peru on a long journey through the South Seas, a group of travellers accidentally come upon an uncharted island which has a mysterious culture. Called Bensalem, this culture is wonderfully perfect. It is rich, technically advanced, and peaceful. Its citizens are happy. The travellers are at once given luxurious accommodations by the island's leaders and made to feel welcome and comfortable. Then, they are left free to tour the island, to marvel at its beauty and organization. Later that evening, they meet with the island's leader, who reveals to the admiring travellers, the secret of his culture. . . .

5. Divide the class into seven groups.

6. Pass out excerpts from Bacon's *New Atlantis*, **Documents E1-7** one to each group. (Each Document describes one important and admirable aspect of Bensalem's scientific utopia.)

7. Read the following statement to the class from the *New Atlantis*. It is spoken by the island's leader, before he discloses their secrets:

> The purpose of our society is the knowledge of causes and secret motions of things, and the enlarging of the boundaries of human pursuits, so that we may accomplish all things possible.

8. Group members discuss their document among themselves, appointing a scribe to take notes. (10 minutes)

9. Class reassembles, and each group reports on their document. Each group should be able to see at least one modern discovery or invention prefigured in Bacon's utopian society. These inventions should be listed on the board by the teacher as the various groups report. Bacon's faith in science as the answer to all of society's problems can be noted by the teacher.

10. Pass out **Document F** to the class, which is Bacon's vision of an organization for scientific work, which promotes and funds research and experimental investigation for the betterment of society.

11. Have individual students read each point.

12. Class discussion on the importance of having an official organization, sanctioned by the government, in which scientific achievement is publicized and rewarded. (However, what might be the drawbacks of regimentation and control?) Discussion of the founding of the Royal British Society in London in 1660, and the French Academy of Sciences in Paris in 1666, which were inspired by Bacon's book. (See **Background Notes to Teacher**) What organizations do we have in the United States which are similar today? (National Academy of Sciences, National Science Foundation, local, regional and national science fairs)

13. Project the Frontispiece from Bacon's *Instauratio Magna*, **Illustration 6**, with an overhead projector. Discuss how this image reflects Bacon's beliefs in the value of science. (Science shown as the

vehicle [ship] which will lead society over the choppy and dangerous seas of ignorance; ship also has direction, is moving away from land toward an uncharted destination [progress]?)

Day Two

1. Pass out **Documents G-1**, an excerpt from Descartes' Discourse on Method and **G-2**, a simplified version.

2. Have different students read aloud from the documents.

Discussion Questions:

a. How does Descartes begin his solution to a problem? (Make sure that basic premise is true, for example, that oil is heavier than water.)

b. Ask students what type of things they would know for sure. (That they are thinking about this question, that they are in school, that they are breathing; these type of primary truths.)

c. What don't they know for sure? (That the earth is round, that Mars has canals, etc. These "truths" are taken on the authority of somebody else. So, applying this first rule, when Descartes was presented with a scientific problem, he would only assume as true the most obvious things, for example, that water was indeed a liquid, that a ball was indeed round.)

d. What is his next step? (To carefully divide up a complex problem into simple parts.)

e. And then? (To arrange these parts from the simplest to the most difficult, doing the simplest first.)

f. Why was it important to keep complete notes of every logical step he took in solving a problem? (To be able to duplicate the procedure with another problem.)

g. What is deductive reasoning? (From one true or "undoubtable" general law, a true or "undoubtable" particular case will follow.)

h. What is the one big change Descartes wants people to make in how they approach problem solving? (To stop taking things on faith in ancient authorities, and rather, to conduct basic investigations based on their own logical powers.)

3. Put the following logical diagram for Deductive Logic on the board, distilled from Descartes.

Diagram for Deductive Logic

All animals eventually die.
A cat is an animal.
Therefore, a cat will eventually die.

Question: What is the inherent danger of this type of reasoning? ***Answer:*** That the general law has exceptions and is not always true. For example:

All cats have tails.
Fluffy is a cat.
Fluffy has a tail.

(But what if Fluffy is a Manx? This is an example of the sort of incorrect starting principle Descartes was concerned about. If your basic starting hypothesis is incorrect, everything you deduce from it will also be incorrect.)

4. Pass out **Document H**, "The Scientific Method," to the class.

7. Discuss process for problem solving. Show the Scientific Method as a logical method which can be adapted for a wide range of problem solving, from scientific to social.

8. **Homework:** Have students use **Document H** to re-do the homework assignment from **Lesson Two**. The assignment is not to solve the problem they have chosen, but simply to formulate a plan of attack using the scientific method adapted to their specific problem.

D. Vocabulary

Day One

coagulation
dissection
distillation
hypothesis
inoculation
meteorological
perspective
prefigure
prism
prolongation
reflection
refraction
stagnation
utopia

Day Two

deductive logic
formulate
hypotheses
scientific method
verification

F. Pronunciation Key

Descartes (DAY-CART)
Cogito ergo sum (KO-GEE-TOE AIR-GO SOOM)

G. Evaluating the Lesson

Informal assessment of class discussion and group work.

From Francis Bacon, *Instauratio Magna* of 1605–1620

Since . . . satisfaction with the present induces neglect of provision [preparation] for the future, it becomes absolutely necessary, that the excess of honour and admiration with which our existing stock of inventions is regarded be . . . stripped off, and men be duly warned not to exaggerate or make too much of them. For let a man look carefully into all that variety of books with which the arts and sciences abound, he will find everywhere endless repetitions of the same thing, varying in the method of treatment, but not new in substance, insomuch that the whole stock, numerous as it appear at first view, proves on examination to be but scanty.

. . . Observe also, that if sciences of this kind had any life in them, that could never have come to pass which has been the case now for many ages — that they stand almost at a stay, . . . [and] what was a question once is a question still, and instead of being resolved by discussion is only fixed and fed; and all the tradition and succession of schools is still a succession of masters and scholars, not of inventors . . . [N.B. "inventor" = discoverer (in Latin *invenio*) not inventor in our modern sense.]

Some there are indeed who have committed themselves to the waves of experience, and almost turned mechanics; [N.B. "mechanic" = practical artisan] yet these again have in their very experiments pursued a kind of wandering inquiry, without any regular system of operations. And besides they have mostly proposed to themselves certain petty tasks, taking it for a great matter to work out some single discovery; — a course of proceeding at once poor in aim and unskillful in design.

As for those who have given the first place to Logic, . . . they have indeed most truly and excellently perceived that the human intellect left to its own course is not to be trusted . . .

For my own part at least, in obedience to the everlasting love of truth, I have committed myself to. . . . the hope of providing at last for the present and future generations guidance more faithful and secure.

I, . . . dwelling purely and constantly among the facts of nature. . .

. have established for ever a true and lawful marriage between the empirical and the rational faculty [in other words, between knowledge based on practical experience and knowledge based on logic]. . . . I contrive [declare] that the office [role] of the sense[s] shall be only to judge the experiment, and that the experiment itself shall judge the thing [should be the judge of the truth or success of an hypothesis]. . . . Those . . . who aspire not to guess . . . but to discover and know; who propose not to invent . . . fabulous worlds of their own, but to examine and dissect the nature of this very world itself; must go to facts themselves for everything. . . .

For man[kind] is but the servant and interpreter of nature; what he does and what he knows is only what he has observed of nature's order. . . .

Reprinted by permission of Macmillan Publishing Company from Francis Bacon, *Essays, Advancement of Learning, New Atlantis, and Other Pieces*, edited by Richard F. Jones (New York: Odyssey Press, 1937; copyright renewed ©1965), pp. 243-264.

Modern Version of Bacon's *Magna Instauratio* (1620)

When people are content with the present, they do not make plans for the future. I think that it is necessary to question our contentment and warn everyone not to be so satisfied with the present. Because if you look carefully around at all the books we now have on art and science, you will find that they contain nothing new, and say only the same things over and over.

Also, our knowledge of science has not progressed at all, and the same old questions remain unanswered. Instead of discussing ideas, and coming up with new answers to problems, our schools are just teaching the same old things.

There are a few people who do conduct experiments and invent things, but when they do, they don't follow a standard set-by-step procedure in their work or a well-planned overall strategy. They also work on projects that are not very important.

People who are interested in working on important things, begin their research by simply reading the same old books that other people have written on subject, and don't do any new research on their own. People do not have faith in their own abilities to figure things out.

What I would like to do is to suggest a new method people can follow when they want to work on an important problem This way, our knowledge of science will progress.

I believe that people should restrict themselves to recording the results of carefully-designed experiments. The experiments themselves will show whether a hypotheses is true or false. Those scientists who don't want to be just guessing, but really to be able to discover and know things, must rely not on someone else's previous conclusions, but on their own factual evidence for everything.

Caves and Towers

We have large and deep caves of several depths, . . . some of them are dug and made under great hills and mountains . . . over three miles deep. . . . we use them for all coagulations, hardenings, refrigerations, and conservations of bodies. We use them likewise for the . . . producing of new artificial metals. We use them also sometimes (which may seem strange) for the curing of some diseases and for prolongation of life in some hermits that choose to live there, who are well accommodated and outfitted with all things necessary.

We have high towers, the highest about half a mile in height, and some of them likewise set upon high mountains, . . . the highest of them three miles at least. . . . We use these towers, according to their several heights and situations, for exposure to the sun, refrigeration, conservation, and for the viewing of various meteorological phenomena, such as winds, rain, snow, hail, and some of the fiery meteors [comets] also.

Lakes, Wells, and Weather

We have great lakes both salt and fresh, which we use for the fish and fowl. We use them also for burials of some natural bodies, for we find a difference in things buried in earth or in air below the earth and things buried in water. We have also pools, some of which strain fresh water out of salt, and other by art [artificially] turn fresh water into salt. . . . We have violent streams and cataracts, which serve us for many motions, and likewise engines for multiplying and intensifying winds . . .

We have also a number of artificial wells and fountains, made in imitation of the natural sources and baths, treated with copper sulfate, sulphur, steel, brass, lead, potassium nitrate, and other minerals. And again we have little wells in which many things may be dissolved. . . . and among them we have a water which we call Water of Paradise, made [for] health and the prolongation of life.

We have also great and spacious houses, where we imitate and exhibit meteorological phenomena, as snow, hail, rain . . .

We have also fair and large baths of several mixtures for the cure of diseases and the restoring of man's body . . .

ORCHARDS,GARDENS, AND PARKS

We have also large and various orchards and gardens. . . . In these we practice all theories of grafting and inoculating. . . . And we make in the same orchards and gardens trees and flowers to come earlier or later than their seasons, and to come up and bear more speedily than by their natural course they do. We make them also larger than their nature; and their fruit larger and sweeter and of differing taste, smell, color, and shape, from their nature. And many of them we change so they can be of medicinal use.

We have also parks and inclosures of all sorts of beasts and birds, which we use not only for view or rareness but likewise for dissections and experiments, that thereby we may learn what may happen on the body of man. . . . We try also all poisons and other medicines upon them, as well as surgery. . . . By experimentation we make them bigger or taller than their kind is, or contrariwise dwarf them, and stunt their growth. . . . we make them differ in color, shape, activity. . . .

Food and Medicine

"I will not hold you long with telling of our brew-houses, bake-houses, and kitchens, where are made different drinks, breads, and meats, rare and with special effects. Wines we have of grapes, and drinks of other juice of fruits, or grains, and of roots, and of mixtures with honey, sugar, manna, and dried fruits . . . . We have also waters which . . . are indeed excellent drink . . . Breads we have of several grains, roots, and kernels; and some of flesh and dried fish, with different kinds of seasonings, so that some stimulate appetites; some are so nourishing, that many live on them without any other meat. . . . We have some meats also and breads and drinks, which taken by men enable them to fast long after, and some other, that when used, make the flesh of men's bodies more hard and tough, and their strength far greater than otherwise it would be.

"We have dispensaries, or shops of medicines wherein the herbs, drugs and ingredients of medicines [are] in great variety. . . . And for their preparations, we have not only all kinds of subtle distillations and chemical analysis, . . . but also exact forms of compounds, whereby they [are] almost like natural herbs.

Furnaces and Light

We have also furnaces of many kinds, that keep a great assortment of heats: fierce and quick; strong and constant; soft and mild; blown, quiet; dry, moist; and the like. But above all, we have heats in imitation of the sun's and heavenly bodies' heats. . . . [we have] instruments also which generate heat only by motion. . . . and again, places under the earth, which by nature or our efforts, yield heat. These different heats we use, as [we require].

We have also perspective-houses, where we make exhibits of all lights and radiations, and of all colors; and out of things uncolored and transparent we can show you all several colors, not in rain-bows, as it is in gems and prisms, but by themselves. We [make] also all multiplications of light, which we carry to great distance, and make so sharp as to see small points. . . . We find also different means, yet unknown to you, of producing light from different things. . . . We have also helps for the sight, far above the spectacles and [eye]glasses in use. We have also glasses and means to see small and minute bodies perfectly and distinctly, as the shapes and colors of small flies and worms, grains and flaws in gems, which cannot otherwise be seen. . . . We make artificial rain-bows, halos, and circles about light. We represent also all manner of reflections, refractions, and multiplication of visual beams of objects.

We have also precious stones of all kinds, many of them of great beauty and to you unknown; crystals likewise; and glasses of different kinds; and among them some of metals made into glass . . .

Sounds and Smells

We have also sound-houses, where we practice and exhibit all sounds and their generation. We have harmonies, which you have not, of quarter-tones. . . . Different musical instruments unknown to you, some sweeter than any you have. . . . We represent and imitate all sounds . . . and the voices . . . of beasts and birds. We have certain helps which . . . further the hearing greatly. We have also diverse strange and artificial echoes, reflecting the voice many times. . . . We have also means to convey sounds in tubes and pipes, in strange lines and distances.

We have also perfume-houses, where we . . . multiply smells . . . We imitate smells . . . We make different imitations of taste likewise, so that they will [fool] any man's taste. . . . And in this house we have also a candy-making house, where we make all sweets, dry and moist, and different pleasant wines, milks, soups and salads, far in greater variety than you have.

Engines and Machines

We have also engine-houses, where are prepared engines and instruments for all sorts of motions. There we imitate and practice to make swifter motions than any you have, . . . and to make them and multiply them more easily and with small force by wheels and other means, and to make them stronger and more violent than yours are, exceeding your greatest cannons. We [have] also arms and instruments of war, and engines of all kinds, . . . Also fire-works of all variety both for pleasure and use. We imitate also flights of birds; we have made some progress in flying in the air; we have ships and boats for going under water. We have different curious clocks and other [oscillators] and some perpetual motions.

We have also a mathematical house, where are exhibited all instruments of geometry and astronomy, [finely] made.

Bacon's Visionary Scientific Organization on the Utopian Island of Bensalem

1. We have twelve people who sail into foreign countries, who bring us the books, outlines, and patterns of experiments from all other parts.

2. We have three people who collect the experiments which are in all books.

3. We have three people who collect the experiments of all mechanical arts, and also of liberal sciences, and also of other practices.

4. We have three people who try new experiments, such as they think good.

5. We have three people who organize the experiments of the former four into titles and tables, to help us understand them.

6. We have three people who analyze the experiments of their fellows, and try to figure out useful applications for our lives.

7. After different meetings and consultations of our whole number to consider these above-mentioned activities, we have three people who direct new, more advanced experiments, which are more penetrating into nature than the former.

8. We have three others that carry out the experiments so directed, and then report to us on them.

9. Lastly, we have three people who make larger generalizations from the above experiments.

10. We also have meetings, where we discuss which ones of the inventions and experiments which we have made shall be published, and which not.

11. For our ceremonies, we have two very long and beautiful galleries; in one of these we place plans and exhibits of all of the more excellent inventions; in the other we place statues of all principal inventors.

12. For every invention of value we erect a statue to the inventor, and give him a liberal and honorable reward.

13. Lastly, we publish such new profitable inventions as we think good. And we also forecast and warn of diseases, plagues, swarms of hurtful creatures, famine, storms, earthquakes, floods, comets, temperatures, and different other things; and give advice as to what the people may do for their prevention.

René Descartes, Discourse on Method (1637)

As a multitude of laws often only hampers justice, so that a state is best governed when, with few laws, these are rigidly administered; in like manner, instead of the great number of precepts [axioms] of which Logic is composed, I believed that the four following would prove perfectly sufficient for me . . .

The first was never to accept anything for true which I did not clearly know to be such; . . .

The second, to divide each of the difficulties under examination into as many parts as possible, and as might be necessary for its adequate solution.

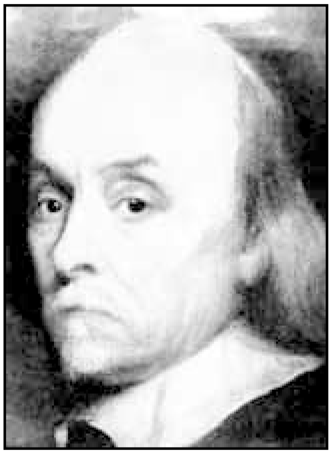
The third, to conduct my thoughts in such order that, by commencing with objects the simplest and easiest to know, I might ascend by little and little, and, as it were, step by step, to the knowledge of the more complex; . . .

And the last, in every case to make enumerations [lists] so complete, and reviews so general, that I might be assured that nothing was omitted.

The long chains of simple and easy reasonings by means of which geometers [people who work with geometry] are accustomed to reach the conclusions of their most difficult demonstrations, had led me to imagine that all things, . . . are mutually connected in the same way, and that there is nothing so far removed from us as to be beyond our reach, or so hidden that we cannot discover it, provided only we abstain from [avoid] accepting the false for the true, and always preserve in our thoughts the order necessary for the deduction of one truth from another.

René Descartes, *Discourse on Method*, translated by John Veich (Edinburgh: William Blackwood and Sons, 1873), pp. 61-62, 74-77, 83-87, 96-100.

Modern Version of Descartes' Discourse on Method



René Descartes

Because too many laws often get in the way of justice, a country is best guided by having a few laws which are strictly enforced. In the same way, instead of following many rules of logic, I have decided to narrow it down to four rules, which work very well for me.

First of all, I have decided never to believe something is true unless I know it for certain.

Secondly, I will divide each thing which I do not understand about the problem into as many parts as possible so that I can begin to solve them one by one.

Third, I will start with the easiest and most simple part of the problems, and work through to the most difficult and complex parts, until I have solved the whole problem.

Lastly, I will keep complete notes of the method of investigation I have used and of the results I have reached, so that I am sure I have not forgotten anything.

The logical procedure used by people who work in geometry, is to begin with the simplest problem and work through to the most difficult. This lets them solve their most complex problems easily. Using them as a good example, it seems to me that there is nothing too difficult in the world to understand if we will only remember two things: One, to stop blindly accepting as true those things we are unsure about, and two, to always investigate problems using a step-by-step procedure which will allow the deduction of one truth from another.

Sir Francis Bacon

Sir Francis Bacon, *Essays, Advancement of Learning, New Atlantis, and Other Pieces*, editedby Richard Foster Jones (New York: The Odyssey Press, 1937).

Frontispiece to Sir Francis Bacon's *Instauratio Magna*

Courtesy of William Andrews Clark Memorial Library

The Scientific Method

1. Statement of the problem.

2. Collection of information on the problem.

3. Organization of the information, putting it into some meaningful order and analyzing it.

4. Hypotheses [tentative solutions] are made of problem on the basis of information.

5. Deductions are drawn from the hypotheses. (If A and B are true, then C must be true)

6. Checking, or verification of hypotheses.

Lesson Four
The Development of the Microscope

A. Objectives

1. To learn about the invention of the microscope, which opened up a whole new world of life, hitherto invisible to human eyes.

2. To understand the critical social role of the Royal Society in London in helping to underwrite and disseminate new scientific discoveries.

3. To come to see the significance of this invention and those men who made use of it, to microbiology and medicine.

B. Historical Background

The country of the Netherlands, beginning in the early 1500s, became famous for its religious and intellectual tolerance. It played host not only to many fugitives from religious and social persecution, published controversial books like Galileo's *Dialogue on the Two Great World Systems* in 1632, (which had met with resistance from Church authorities in Italy), but also produced among its native sons, a flowering of speculative and inventive activity. From Erasmus of Rotterdam to Spinoza and, the Dutch made unique contributions to the spirit of discovery that characterized the Scientific Revolution. One native son of the Netherlands was Anton van Leeuwenhoek, a linen merchant, who as an amateur scientist, became the founder of the field of microbiology, using his humble, home-made microscope.

Magnifying devices were not new to the 16th century. They had been around since at least 65 A.D. At that time, Seneca had suggested using glass globes to magnify images and concentrate light. At the beginning of the 1300s, spectacles were invented by Italian glassworkers. Galileo had even had a magnifying device. In 1624, he wrote to a nobleman, "I send Your Excellency an 'occhiale' [eyeglass] by which to see close the smallest things. I have contemplated very many animals with infinite admiration, amongst which the flea is most horrible." A year later, fellow Italian Giovanni Faber invented the word "microscope".

Compound microscopes which consisted of two lenses superimposed over one another, probably existed by 1590. One of the first fabricators of this type of microscope was the Dutchman Zacharias Janssen, a spectacle-maker from

Middleburg. His first microscope of the early 1600s was described by a friend as having a gilded brass tube two inches in diameter, and almost eighteen inches long. The tube itself was mounted on three brass dolphins which stood on a base of ebony wood. In 1625, the Italian Francesco Stelluti published his studies of a honeybee, as viewed through this type of microscope.

The newly-established Royal Society of London then played a crucial role in creating increased interest in the microscopic realm. In 1662, only two years after its founding, the Royal Society named Robert Hooke as its curator of experiments. He was a 27-year-old scientist out of Oxford, who had been assistant to the famous scientist, Robert Boyle, known for his work on the expansion of gases. Hooke was interested in microscopes, and the Society arranged for him to do a series of weekly demonstrations of his discoveries with the device. Hooke's book of observational drawings, the product of these weekly presentations, appeared in 1665. Entitled *Micrographia*, it was published by the Royal Society. The miniature world which this book displayed created a rush of public interest in this hitherto esoteric field of inquiry.

One man who saw Hooke's book and was fascinated by this "invisible" microscopic world, was the draper from Delft, the Dutchman Anton Van Leeuwenhoek (LAY-WEN-HOOK) (1632-1723). In 1683, a young anatomist who was a friend of Leeuwenhoek's in the Netherlands, wrote to the Royal Society's secretary in London that Leeuwenhoek was a "most ingenious person" who had made a better microscope than the compound microscopes in general use. A further letter to the Society from another acquaintance described Leeuwenhoek as "a person unlearned both in sciences and languages, but of his own nature exceedingly curious and industrious . . . as you shall see by his cleere [clear] observations . . . " Enclosed with the letter were drawings made of what Leeuwenhoek had been able to view through his humble, but effective, simple microscope. In spite of his lack of formal training, Leeuwenhoek, over the course of his life, was the first person to observe and draw cells, and to identify the cell nucleus. In one of his first letters to the Society, he described himself in the following way: " . . . I have no style or pen with which to express my thoughts properly; . . . I have not been brought up to languages or learning, but only to business . . . " His correspondence with the Society spanned more than thirty years, and his letters, full of discoveries, were regularly published.

By hand-grinding lenses with magnifying powers up to 270 diameters, he had made his own viewing devices. His simple microscope (so-called because it used only one lens), was not much to look at. It consisted of a single bead of glass mounted between two thin plates of metal, with a screw apparatus on one side to hold and position specimens (See **Illustration 8**). With this device, small enough to fit into the palm of his hand, Leeuwenhoek described the "animalcules" (tiny animals) he saw as being 1,000 times smaller than the eye of a louse, which he used as a standard measurement because its size was remarkably constant. Leeuwenhoek, through his pioneering work with his microscope, made breakthroughs that other researchers, using more complicated devices could not achieve. He went on to discover bacteria, and also advanced the science of embryology, that is, the study of embryos and their development. His work had far-reaching consequences for the field of medicine, but equally as important, brought to human beings a sense of wonderment and kinship with the miniature world of microscopic creatures.

C. Lesson Activities

1. Pass out **Document I**, "Leeuwenhoek's Letter to the Royal Society" (which most students should find interesting). Give the class time to read the document.

3. Ask the Class for their interpretation of the document. Suggestions for discussion:

    a. What is Leeuwenhoek in the process of discovering? (Bacteria.)

    b. What process can you see unfolding? (Scientific experimentation in progress.)

    c. Where have we seen a similar amazement at seeing an unknown world? (Galileo's first view of craters on the moon, in the **Dramatic Moment**.)

    d. What has scientific experimentation provided for human beings? (Dramatic expansion of human consciousness from macrocosm to microcosm.)

4. Use an overhead projector to show **Illustration 7**, the portrait of Leewenhoek, and **Illustration 8**, the illustration of Leeuwenhoek's Simple Microscope to the class. Share with the class the story about Robert Hooke and Anton Leeuwenhoek, briefly outlined in the **Historical Background**.

5. Again, drawing on the **Historical Background**, share with the class the crucial role played by the Royal Society in London (introduced in **Lesson Three**) in both Hooke's and Leeuwenhoek's contributions to science.
6. Divide the class into five groups.

7. Pass out to the groups **Illustrations 9** through **13**. (Drawings, and in one case, an actual photograph, made from observations through microscopes by Robert Hooke, Anton Leeuwenhoek, and Francesco Stelluti).

8. Each group discovers features of their drawing that would be invisible to the human eye without the use of a microscope, and appoints a scribe to list them.

9. The class reassembles, and each group presents to the class their findings. Have a class discussion on the implications of the microscopic world for science and society in general. (Discovery of bacteria and its link to disease; discovery of plant structures, and their regenerative capabilities; basic appreciation of the beauty of miniature structures, heretofore unseen; a new connectedness to creatures too small to be seen before, or craters on the moon being too far away to see; a new sense of our being somewhere at the midpoint in size, a re-establishment of the geocentric universe we began with?)

10. Share with the class Leeuwenhoek's appreciative comments on a moth, and his inability to share in the common belief that such creatures were created out of decaying matter. (**Document J**).

D. Vocabulary

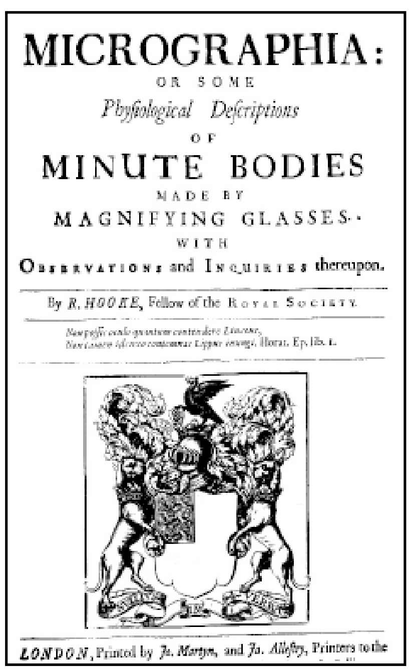
animalcules
bacteria
ingenious
macrocosm
microbiology
microcosm
occhiale
propagate
regeneration
spores

E. Pronunciation Key

Giovanni Faber	(GEE-OH-VAHN-EE FAH-BARE)
Zachiarias Janssen	(ZAHK-ARE-I-AS YAHN-SEN)
Robert Hooke	(HOOK)
Anton van Leeuwenhoek	(AHN-TAWN FON LAY-WEN-HOOK)
occhiale	(OAK-E-AHL-AY)
Francesco Stelluti	(FRAHN-CHES-KO STAY-LOO-TEE)

F. Evaluating the Lesson

Informal observation of group work and contribution to class discussions.


MICROGRAPHIA:
OR SOME
Physiological Descriptions
OF
MINUTE BODIES
MADE BY
MAGNIFYING GLASSES.
WITH
OBSERVATIONS and INQUIRIES thereupon.

By *R. HOOKE*, Fellow of the ROYAL SOCIETY.

[illegible]

LONDON, Printed by *Jo. Martyn*, and *Ja. Allestry*, Printers to the

Letter from Anton van Leeuwenhoek, Published in The Proceedings of the Royal Society of London, ca. 1683.

In my letter of the 12th of September 1683, I spoke among other things, of the living creatures that are in the white matter which lies betwixt [between] . . . one's front teeth or one's grinders. Since that time . . . I have examined this stuff many times; but to my surprise, I could discover no living creatures in it.

Being unable to satisfy myself about this, I made up my mind to . . . look into the question as carefully as I could. But because I keep my teeth uncommonly clean, rubbing them with salt every morning, and after meals generally picking them with a fowl's quill, or pen; I found very little of the stuff stuck on the outside of my front teeth; and in what I got out from between them, I could find nothing with life in it. Thereupon I took a little of the stuff that was on my . . . grinders; but though I had two or three shots at these observations, it was not till the third attempt that I saw one or two live animalcules. . . .

Having allowed my speculations to run on this subject for some time, methinks I have now got to the bottom of the dying-off of these animalcules. The reason is, I . . . pretty near always in the morning drink coffee . . . so hot that it puts me into a sweat: . . . Now the animalcules that are in the white matter on the teeth . . . being unable to bear the hotness of the coffee, are thereby killed . . .

Accordingly, I took (with the help of a magnifying mirror) the stuff from off the teeth further back in my mouth, where the heat of the coffee couldn't get at it. . . . and then I saw with as great a wonderment as ever before, an inconceivably great number of little animalcules, and in so unbelievably small a quantity of the foresaid stuff, that those who didn't see it with their own eyes could scarce [believe] it. These animalcules, or most all of them, moved so nimbly among one another, that the whole stuff seemed alive and all moving.

ANTON LEEUWENHOEK

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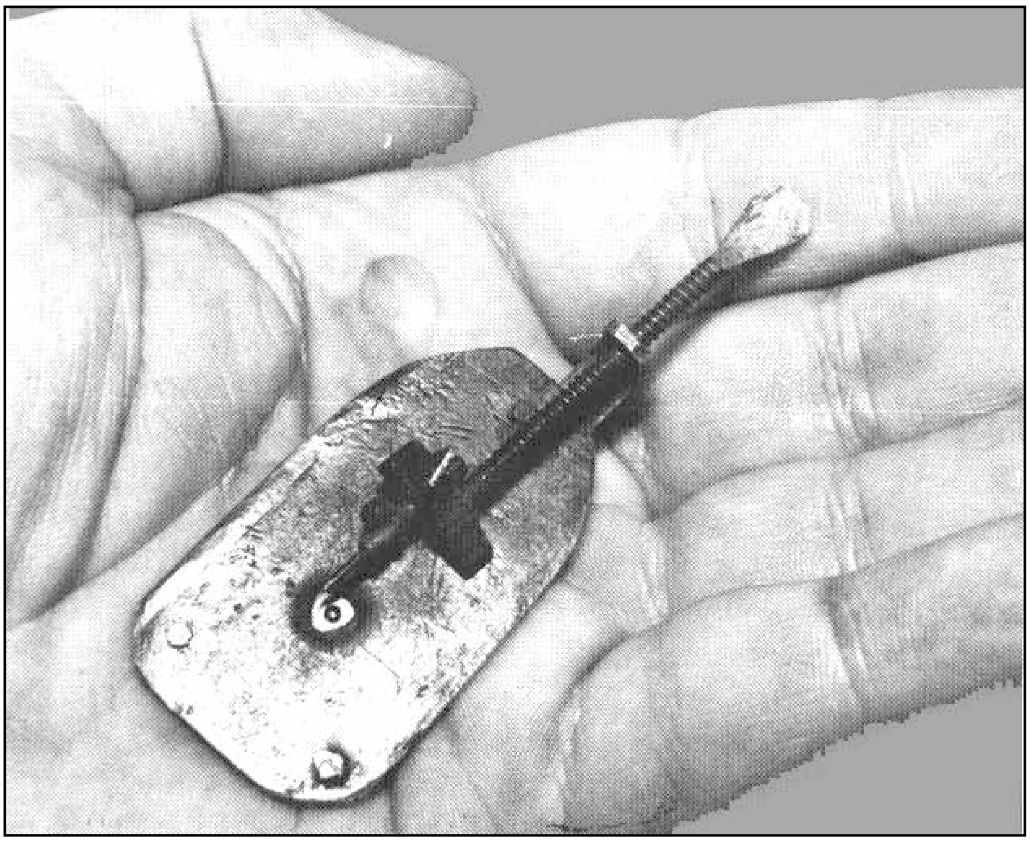
The Leeuwenhoek Microscope



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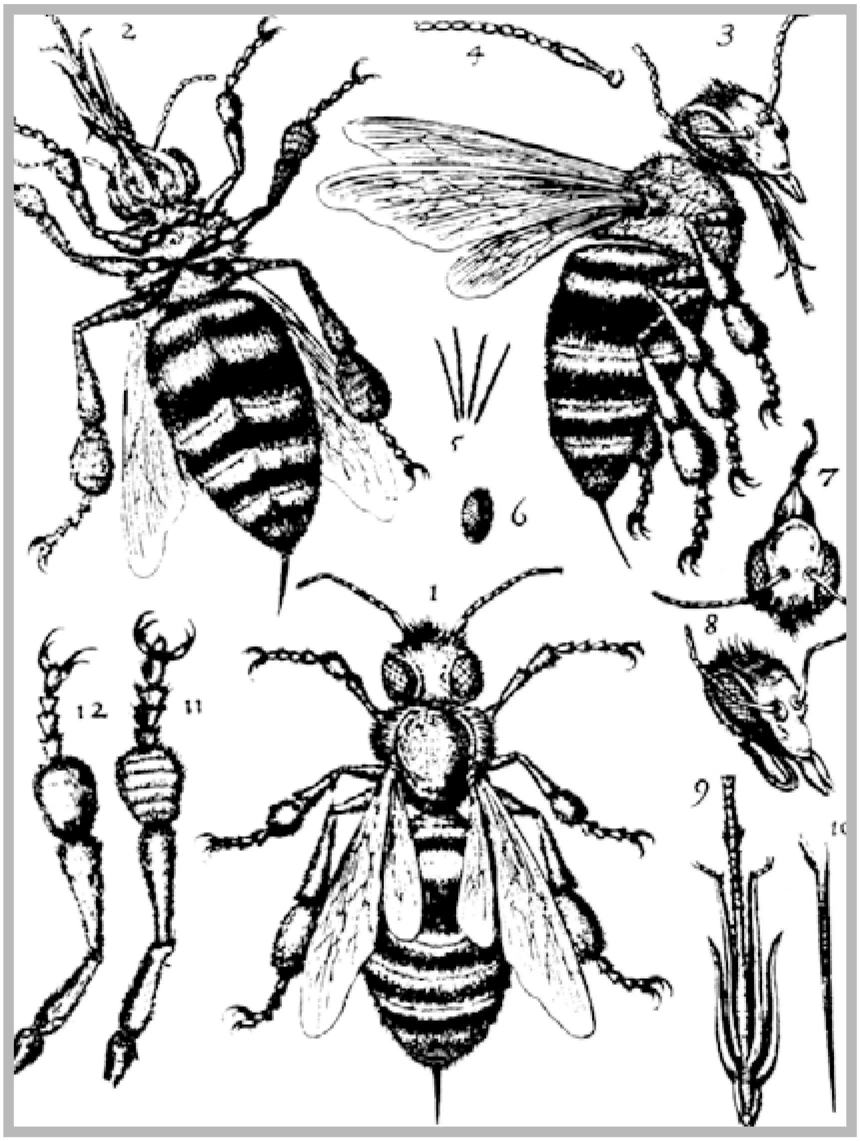
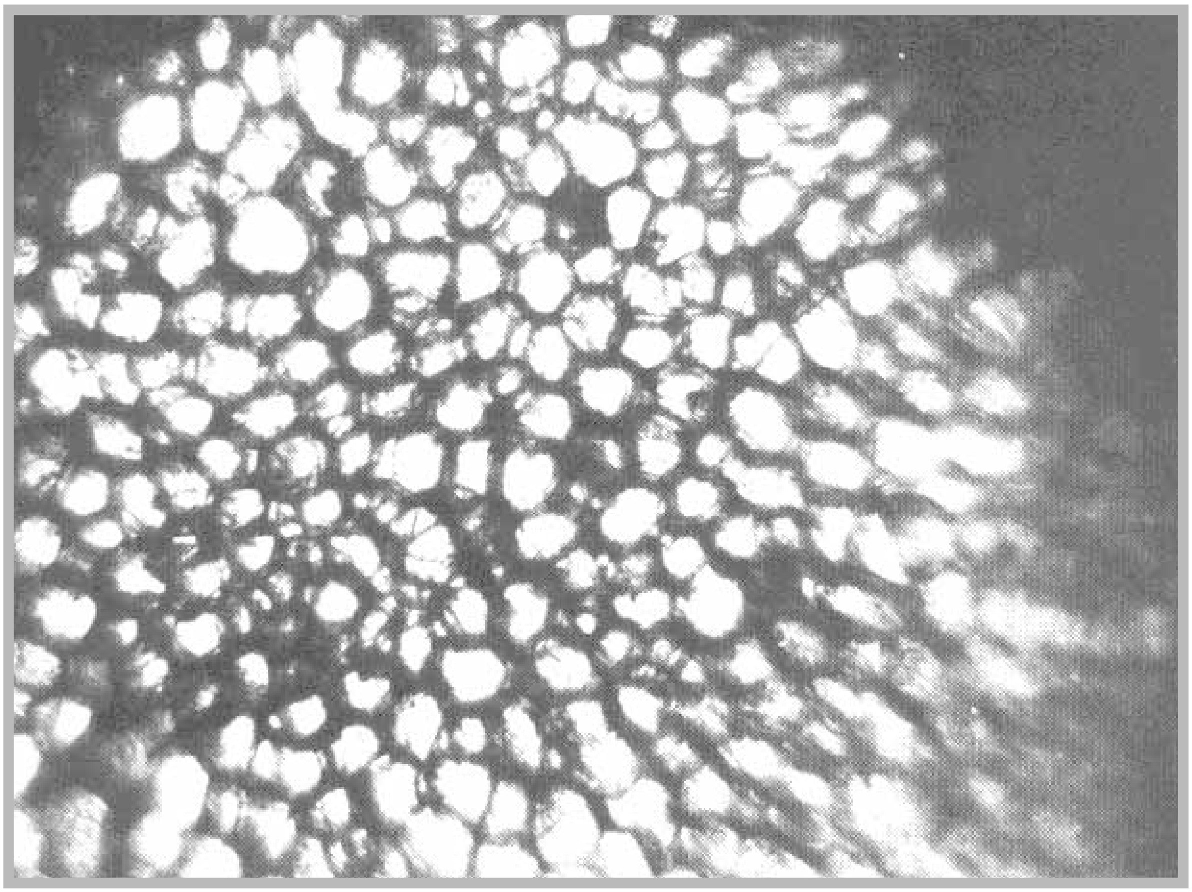
HONEY BEES



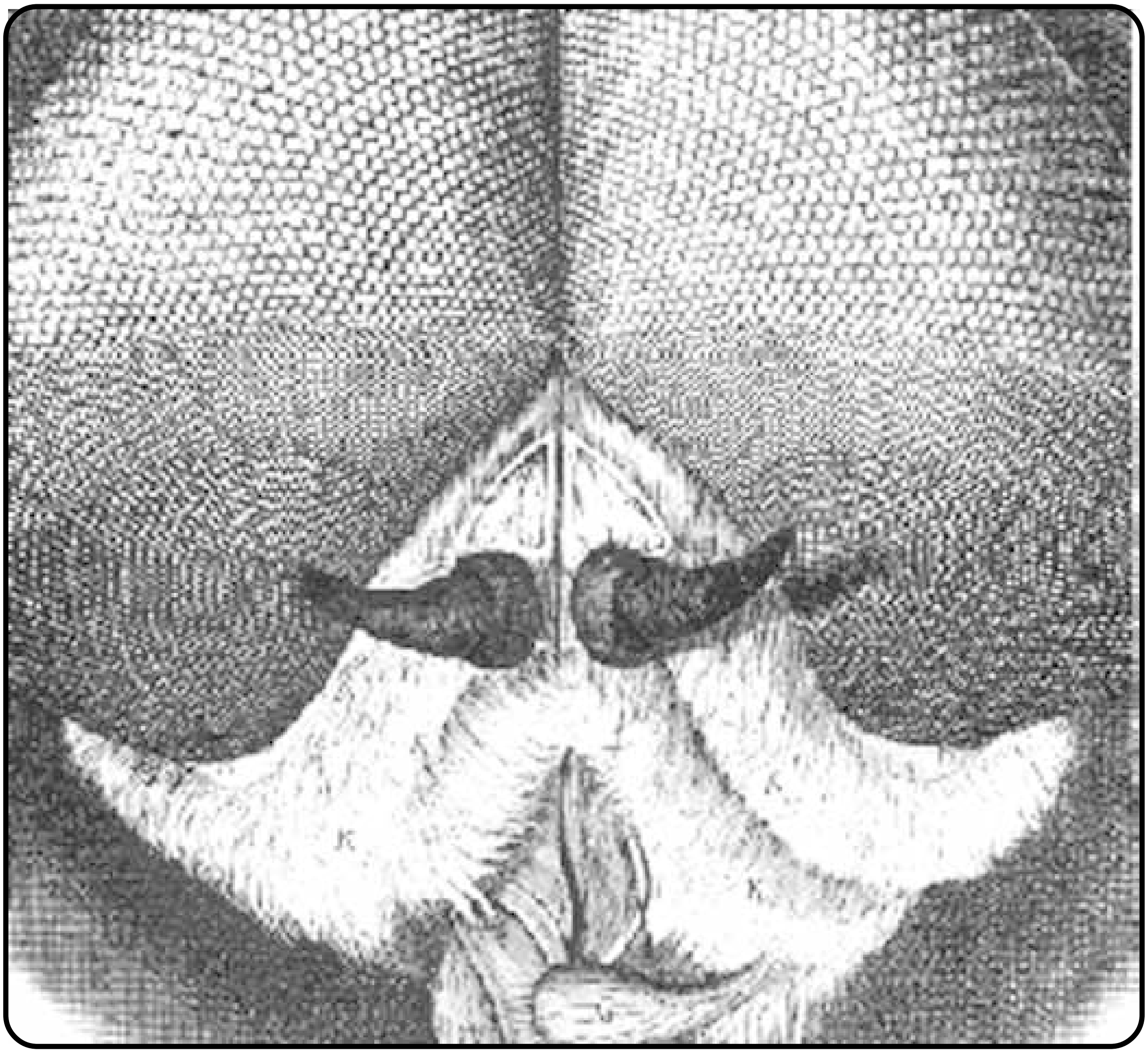
From Francesco Stelluti, *Descrizzione dell'Ape* (1625). Reprinted as published in *Single Lens: The Story of the Simple Microscope*, by Brian J. Ford, copyright 1985, with the kind permission of, Heinemann, London.

Section of Cork



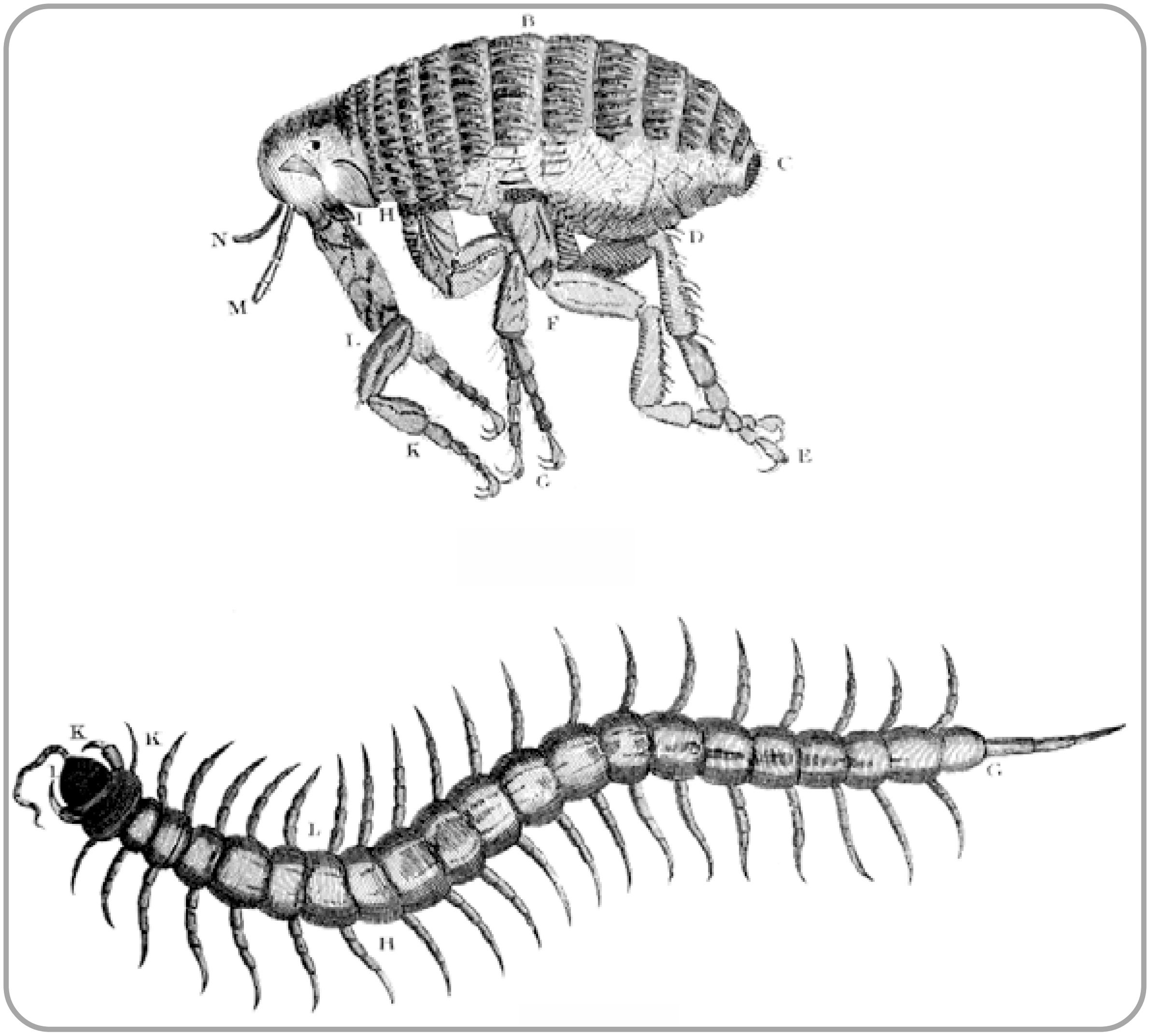
From photograph taken by Brian Ford of a cork section actually used by Leeuwenhoek. Photo was made through Leeuwenhoek's own microscope at Museum in Utrecht. Reprinted as published in *Single Lens: The Story of the Simple Microscope*, by Brian J. Ford, copyright 1985, with the kind permission of, Heinemann, London.

Insect Eyes



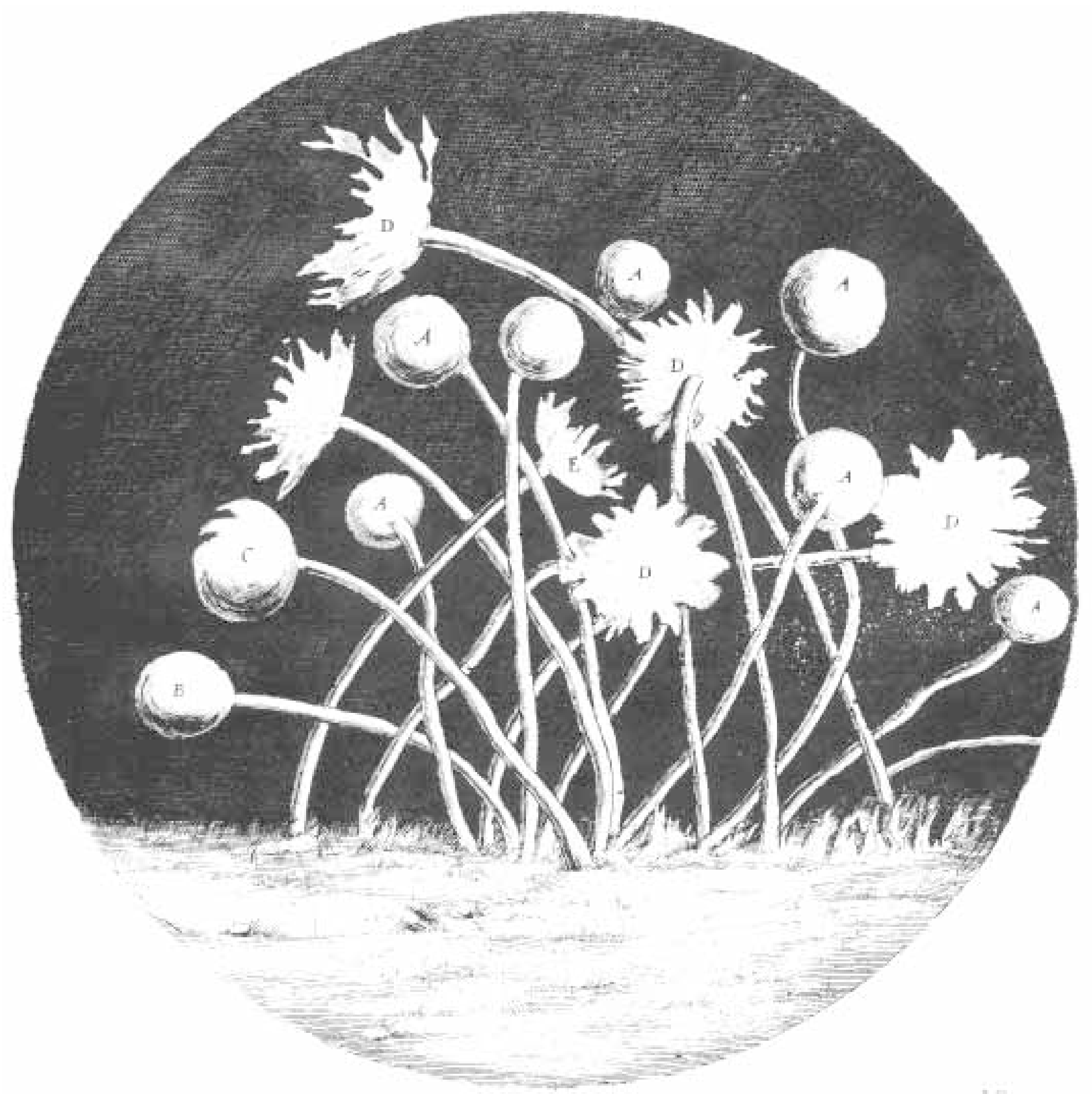
From Robert Hooke, *Micrographia* (1665). Reproduced as published in *The Atlas Catalogue of Replica Rara Antique Microscopes*, by J.B. McCormick and Gerard Turner, copyright 1975, with the kind permission of the copyright owner, Republica Rara Limited, Chicago.

Flea and Centipede



From Anton van Leeuwenhoek, unidentified publication ca 1680. From Robert Hooke, *Micrographia* (1665). Reproduced as published in *The Atlas Catalogue of Replica Rara Antique Microscopes*, by J.B. McCormick and Gerard Turner, copyright 1975, with the kind permission of the copyright owner, Republica Rara Limited, Chicago.

Spores



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A Letter to the Royal Society from Leeuwenhoek, Mid-1600s

Leeuwenhoek's Description of a Common Moth

Can any man in his sober senses imagine that a moth . . . which is duly provided by nature with the means to propagate its species, furnished with eyes exquisitely formed, with horns, with tufts of feathers on its head, with wings covered with such multitudes of feathers all of different shapes, and they covering the wings in every part; can this moth, I say, adorned with so many beautiful features, be produced from decay? For in a word, in this little creature — contemptible as it seems to humans — there shines forth so much perfection and skill in formation as to exceed what we imagine in larger animals.

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