THE NEW JERSEY
ITALIAN HERITAGE COMMISSION

It's the Question That You Ask

Galileo Galilei

Grade Level: 6-12

Subject: Science / World History / World Languages

Categories: Arts and Sciences / History and Society

Standards:

Please see page 8 of the lesson plan for complete New Jersey Student Learning Standards alignment.

Objectives:

Students will be able to:

1. explain why the proper question can lead to a more accurate answer.
2. conduct an experiment using the scientific method.
3. demonstrate why scientific experiments will explain the "how" things happen.

Materials:

- Five five-pound free weights and one ten-pound weight
- A high place, e.g. football stands, second floor window.
- Duct tape
- Notebook

Abstract:

The lesson includes Galileo's investigation of gravity. It emphasizes the shift from Aristotelian deductive reasoning to empiricism by changing the investigative question from why things fall to earth to how things fall to earth.

Background:

Ancient Greece gave birth to systematic thinking, i.e., philosophy. Through philosophy, men began to use reason and the observation of the natural world to explain the causes of things. Aristotle brought his mentor, Plato's abstract investigation of causes to his own investigation of the physical world. Aristotle, however, did not conduct scientific experiments in the modern sense. Like other Greek philosophers, he believed that all knowledge could be deduced through reason.

Aristotle reasoned that the cause of falling was "heaviness." He deduced that the heavier an object, the faster it would fall to earth.   To Aristotle, the world was made up of combinations of the four elements, Earth, Fire, Air, and Water. Since dense, heavy objects were primarily made of Earth, they would naturally return to where they belonged -- on the earth. The heavier an object (or more full of Earth), the more quickly it returned to its proper place, laying on the earth.

Aristotelian thought became the dominant, unquestioned way of looking at the world during the late Middle Ages. Seventeenth-century Italian scientist Galileo Galilei, however, changed the way the West looked at gravity and how it looked at the world in general.

Galileo proposed that all objects fall back to Earth at the same speed, regardless of their weight. He did not look for causes, as Aristotle had. He did not want to understand “why things fall to Earth;” rather, he wanted to know, “how things fall to Earth.” By changing the question, Galileo changed the understanding of gravity and greatly contributed to humanity’s understanding of the world.

<u>Procedures:</u>

I. Do not give students the above background until after the lesson.

II. Ask students, from previous observations, what would fall faster to earth, a five-pound weight or a twenty-pound weight.
   a. Have them record their hypothesis in their notebook.
   b. Have them record why they came to their determination.

III. Tell students that legend reports that Galileo went to the top of the Leaning Tower of Pisa and dropped a ten-pound weight and a one-pound weight to Earth to prove his own hypotheses.*

IV. Explain to students that you are going to conduct a similar experiment at school.
   a. Have students write the procedures in their notebooks, directly under their hypothesis and reasoning.
      1. They will need five five-pound free weights from the weight room.
      2. Have some students go to a high place at the school. Maybe the back of the football stands, or to a second floor window will provide the proper venue.
      3. Have students stand nearby (but not under the weights) below the high place to record their findings.
      4. Drop two five-pound weights at the same time, from a dead stop. Students will record in their notebooks whether they hit the ground at the same time.
      5. Lightly tape two five-pound weights together (a 10lb. object).
         a. Drop the two lightly taped five-pound weights and a five-pound weight from a dead stop.

* Galileo never claimed to have performed the experiment from the Leaning Tower. Had he actually conducted the experiment, most science historians believe, he would have recorded it in his notes.

b. Students will record in their notebooks whether they hit the ground at the same time.

6. Drop a five-pound weight and a ten-pound weight, from a dead stop. Students will record in their notebooks whether they hit the ground at the same time.
7. Tape four five-pound weights together (a 20lb. object).
    a. Drop the four taped five-pound weights and a five-pound weight, from a dead stop.
    b. Students will record in their notebooks whether they hit the ground at the same time.

V. Tell students that Aristotle predicted that from a prefect stop, a ten-pound weight would fall ten times faster than a one-pound weight. Ask them whether that was true.

VI. Tell students that Galileo predicted that from a perfect stop, a ten-pound weight would fall at the same rate of speed as a one-pound weight. Ask them whether that was true.

VII. Give students the background above. Point out that Galileo changed the question and thus changed the world.

VIII. Using the scientific method tries to explain the "how" things happen.

IX. Philosophy tries to explain the "why" things happen.

Assessment:

From their notes, have students write a sequential paragraph explaining the experiment. Students will use their hypothesis as their thesis or main idea. They will then list the procedure in sequential order, and in the conclusion, they will report their results. Assess the paragraph by using the *New Jersey Registered Holistic Writing Rubric* for scoring.

Extension:

Have students research how Isaac Newton used Galileo's law of falling objects to develop the Law of Gravity, which states "*All bodies attract all other bodies, and the strength of the attraction is proportional to the masses of the two bodies and inversely proportional to the square of the distance between bodies,"* less than fifty-years later.

Supplemental Information

Galileo Galilei

Galileo Galilei was born in Pisa, Italy on February 15, 1564. He was the first born of Vincenzo Galilei's and Giulia degli Ammannati's six children. The Galileis were not rich, though they were members of the local nobility. Vincenzo, a musician and music teacher by trade, moved his family to Florence in 1572, though Galileo stayed in Pisa for two additional years.

The ever-precocious Galileo left Pisa at age ten to join his family in Florence; and there, he was tutored by Jacopo Borghini. Once he was old enough to gain admittance, Vincenzo sent Galileo to the Camaldolese Monastery at Vallombrosa, southeast of Florence. The Camaldolese Order was independent of the Benedictine Order, splitting from the Benedictines in 1012. The Order combined the solitary life of the hermit with the strict life of the monk, and soon the young Galileo found he thoroughly enjoyed the contemplative environment. He became a novice, intending to join the Camaldoleses; nevertheless, his father had already decided that his eldest son should become a physician.

In 1582 Galileo began studying medicine at the University of Pisa, at his father's insistence. While at Pisa, Galileo started to investigate movements of the pendulum. According to the myth, he watched a suspended lamp swing back and forth in the cathedral at Pisa. It was not until 1602, however, that Galileo made his most notable discovery about the pendulum. He determined that the period, or the time in which a pendulum swings back and forth, does not depend on the arc of the swing. Eventually, this discovery would lead to Galileo's further study of time intervals and the development of his idea for a pendulum clock.

At the University of Pisa, Galileo learned ancient Aristotelian physics. Aristotle's physics did not engage in scientific experimentation. It determined causes through the use of reason alone. Galileo, however, questioned Aristotle's approach. Aristotelians believed that heavier objects fall faster through a medium (air) than do lighter ones. Galileo eventually disproved this idea by asserting that all objects, regardless of their density, fall at the same rate in a vacuum. To determine this, Galileo performed various scientific experiments in which he dropped objects from certain heights. In one of his early experiments, he rolled balls down a gently sloping inclined plane and then determined their positions after equal time intervals. He wrote down his discoveries about motion in his book, *De Motu*, [*On Motion*].

In 1591 Galileo's father died. As the eldest son, Galileo had to provide financial support for the rest of the family. He also had to obtain the financial means to provide dowries for his two younger sisters. His position as a professor of mathematics at Pisa did not pay well, so Galileo looked for a more lucrative post. With strong recommendations from Guidobaldo del Monte, Galileo was appointed professor of mathematics at the University of Padua in 1592. He now earned a salary of three times that of his Pisa post. The years at Padua were the best of Galileo's life. His duties were mainly to teach Euclidian geometry and geocentric astronomy to medical students. Medical students at that time needed to know some astronomy in order to use astrology in their medical practice. Galileo, however, argued against Aristotle's view of astronomy and natural philosophy, in three public lectures he gave in connection with the appearance of "Kepler's supernova" -- the New Star in 1604.

Scholars at that time agreed with the Aristotelian belief that all changes in the heavens had to occur in the lunar region close to the Earth. The realm of fixed stars was permanent. Galileo used parallax (the difference in direction of a celestial body as measured from two points on the Earth) arguments to prove that the New Star could not be close to the Earth. In a letter written earlier to the German astronomer, Johannes Kepler in 1598, Galileo wrote that he was a Copernican (believer in the heliocentric theories of the Polish priest and astronomer Nicholas Copernicus). No public sign of this belief, however, was to appear until many years later.

Galileo never married, although he did have an illicit relationship with Marina Gamba, a woman he met in Venice. Marina came to live with Galileo in Padua and was the mother of his three children. Galileo's two daughters, Virginia and Livia, were both sent to convents where they eventually became Sister Maria Celeste and Sister Arcangela. In 1610, Galileo moved from Padua to Florence to take a position at the court of the Medici family. He left his son, Vincenzio, with Marina Gamba in Padua. In 1613, Marina married Giovanni Bartoluzzi, and Vincenzio joined his father in Florence.

Galileo invented many mechanical devices such as a pump and the hydrostatic balance. Perhaps his most famous invention, nevertheless, was his telescope. Galileo constructed his first telescope in 1609. He modeled his telescope after a telescope produced in Northern Europe that could magnify objects three times. He created a telescope later that same year that could magnify objects twenty times. With this telescope, he was able to look at the moon, discover four satellites of Jupiter, observe Kepler's supernova, verify the phases of Venus, and discover Sunspots. His discoveries gave strong evidence to support the Copernican system which states that the Earth and other planets revolve around the Sun. Prior to the Copernican system, it was held that the universe was geocentric, meaning the Sun revolved around the Earth.

Galileo first looked at Saturn with his telescope on July 25, 1610, and it appeared to be three separate bodies. His telescope was not good enough to show the rings. It made them look like lobes on either side of the planet. More observations caused him further confusion. The bodies on either side of Saturn disappeared when the rings were viewed head on. Also in 1610 he discovered that the planet Venus showed phases like those of the Moon, and therefore must orbit the Sun not the Earth. This, however, was not conclusive proof of the Copernican system, where everything in the Solar System goes round the Sun. Another contemporary theory, proposed by the Dane, Tycho Brahe, said that all heavenly bodies, save the Earth and Moon, go round the Sun, which in turn goes around the Earth. Most astronomers of the time favored Brahe's system, not Copernicus'. Distinguishing between the two theories by experiment was beyond the instruments of the day. Galileo, however, knew that all his discoveries gave strong evidence for the Polish priest's theory, although he knew they were not conclusive proof.

Galileo's belief in the Copernican system eventually got him into trouble with the Catholic

Church and the Roman Inquisition. Nonetheless, Galileo, himself, must take some of the blame for the confrontation. His arrogance, sardonic words, mocking of opponents, contempt for weaker minds and half-truths had earned him ferocious enemies among many of the intellectuals of Europe--especially among some in the powerful Jesuit religious order.

The second reason the Church disapproved of the Copernican theory was naturalism, the science of the day. Advocates of the pagan philosopher Aristotle resisted Galileo's findings. The Pope and cardinals would not have acted against Galileo, if dozens of these "scientists" had not said Galileo was wrong. This point more than any other led to Galileo's condemnation. He was out of the mainstream of the scientific community of his day. Some scholars hated Galileo, who had acerbically offended them on many previous occasions. Others believed that Aristotle and the Bible should not be overturned without conclusive evidence. Both Kepler and Galileo had shown that the Bible could be interpreted to agree with the new science; nevertheless, the contemporary scientific authorities' own eyes showed them that the Sun, not the Earth moves. Galileo could not provide hard evidence to the contrary. Solid proof for the Earth's movement around the Sun was two hundred years away, when tiny shifts in star positions and subtle pendulum motions were finally measured.

The Roman Inquisition was a permanent institution in the Catholic Church, established in 1542 to combat Protestantism, and it was charged with the eradication of heresies. The worldliness and corruption of the Italian Renaissance of the previous century forced the Inquisition to be very thorough in its investigation and very hesitant to advocate change. The lax ecclesiastical oversight and outright clerical corruption during the Renaissance was blamed for the Protestant theological rebellion against the Church; thus, the Inquisitors were extremely cautious. An Aristotelian worldview, as interpreted by the Scholastic philosophers and theologians had for generations taught that the Sun and the planets rotated around the Earth. The Inquisitors were not ready to open what they saw as a "Pandora's box." Ironically, the Protestant Reformation's literal interpretation of the Bible, led many in the Catholic Church to begin to look at the Bible more literally, and they accepted the Aristotelian view as consistent with the Biblical view.

A committee of consultants declared to the Inquisition that the Copernican proposition that the Sun is the center of the universe was a heresy and contrary to the Bible. Because Galileo supported the Copernican system, he was warned by Robert Cardinal Bellarmine (later Saint Roberto Francesco Romolo Bellarmino), a cardinal in the Roman Catholic Church and a member of the Jesuit order, to change his position. Bellarmine was considered by most to be a great intellect and was later named a Doctor of the Church. Bellarmine was initially well disposed toward Galileo, but Galileo's enthusiasm for the Copernican system led to a falling-out between the two men.

Pope Paul V eventually ordered Galileo to not discuss or defend Copernican theories, in 1616. In 1624, however, Galileo was assured by his friend and sponsor, Pope Urban VIII that he could write about Copernican theory as long as he treated it as a mathematical proposition. Urban VIII (the former Maffeo Cardinal Barberini) had been Galileo's friend and had opposed his condemnation in 1616. As a cardinal, he had provided Galileo with a pension, to which as a foreigner in Rome Galileo had no claim. Barberini (Urban) had conferred the pension in support of Galileo and in support of science. Regrettably, to Galileo's disappointment Urban as Pope would not reverse the former judgment of the Inquisition.

Galileo's book, the *Dialogue Concerning the Two Chief World Systems*, unfortunately, caused Galileo to be recalled to Rome in 1633 to face the Inquisition again. The Inquisition found Galileo guilty of heresy for his *Dialogue.* Galileo confessed his guilt, probably remembering the Neoplatonist, Giordano Bruno whom the Inquisition had burned in 1600 and fellow scientist, Michael Servetus, whom Protestant reformer, John Calvin had burned at the stake in 1553 in Geneva. The Roman Inquisition sent the contrite genius home near Florence, where he was to be under house arrest for the remainder of his life. He abandoned his exploration of the heavens, concentrated his study on motion, and overthrew the Aristotelian view of "motion mechanics." In 1638, the Inquisition allowed Galileo to move to his house in Florence, so that he could be closer to his doctors. By that time he was totally blind. In 1642, Galileo died at his home just of outside Florence.

<u>Sources:</u>

"The Galileo Controversy."
https://www.catholic.com/tract/the-galileo-controversy

John Gerard, transcribed by Carl H. Horst. "Galileo Galilei." *New Advent, Catholic Encyclopedia.*
http://www.newadvent.org/cathen/06342b.htm

Thomas H. Greer and Gavin Lewis. *A Brief History of the Western World.* Hardcore Brace College Publishers, 1997.

J. J. O'Connor and E. F. Robertson. "Galileo Galilei." The MacTutor History of Mathematics Archive, St Andrews University, Scotland.
https://www-history.mcs.st-andrews.ac.uk/Biographies/Galileo.html

Megan Wilde "Biography," *The Galileo Project.*
http://galileo.rice.edu/galileo.html

New Jersey Student Learning Standards

English Language Arts

W.6.3 Write narratives to develop real or imagined experiences or events using effective technique, relevant descriptive details, and well-structured event sequences.

W.6.3c Use a variety of transition words, phrases, and clauses to convey sequence and signal shifts from one time frame or setting to another.

W.7.3 Write narratives to develop real or imagined experiences or events using effective technique, relevant descriptive details, and well-structured event sequences.

W.7.3c Use a variety of transition words, phrases, and clauses to convey sequence and signal shifts from one time frame or setting to another.

W.8.3 Write narratives to develop real or imagined experiences or events using effective technique, relevant descriptive details, and well-structured event sequences.

W.8.3c Use a variety of transition words, phrases, and clauses to convey sequence, signal shifts from one time frame or setting to another, and show the relationships among experiences and events.

W.9-10.3 Write narratives to develop real or imagined experiences or events using effective technique, well-chosen details, and well-structured event sequences.

W.9-10.3c Use a variety of techniques to sequence events so that they build on one another to create a coherent, complete and comprehensive piece.

W.11-12.3 Write narratives to develop real or imagined experiences or events using effective technique, well-chosen details, and well-structured event sequences.

W.11-12.3c Use a variety of techniques to sequence events so that they build on one another to create a coherent whole and build toward a particular tone and outcome (e.g., a sense of mystery, suspense, growth, or resolution).

Science

RST.6-8.3 Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

RST.6-8.5 Analyze the structure an author uses to organize a text, including how the major sections contribute to the whole and to an understanding of the topic.

RST.9-10.3 Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

RST.9-10.5 Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., *force, friction, reaction force, energy*).

RST.11-12.3 Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

RST.11-12.5 Analyze how the text structures information or ideas into categories or hierarchies, demonstrating understanding of the information or ideas.