7.1: Modeling the Moons of Jupiter

This activity will allow your students to recreate Galileo's discovery of the four largest moons of Jupiter. Before you embark on this activity, it is a good idea to acquaint your students, and yourself, with the basic features of the old geocentric model of Aristotle and Ptolemy. Many of the features and ideas represented in this model will seem strange to your students, and even contradict things they have already been taught. Children in the 21st century are the beneficiaries of centuries of scientific struggle and learning; never the less, an understanding of the scientific ideas from Galileo's time can be useful in showing our children how science changes and evolves as new facts and ideas are discovered. This is a key idea in STEM culture and thinking.

The geocentric system of Aristotle has the Earth in the center of everything – and it is completely unmoving; it neither spins on its axis each day, nor does it orbit the Sun every year. In fact, in the geocentric system, ***everything orbits the Earth!*** The Sun, the Moon, the various planets, and even the distant stars all revolve around the Earth at different speeds and distances. It was this idea that everything orbits the Earth which was the first crack in the geocentric theory that Galileo would exploit in his quest to prove the heliocentric system correct.

Academic Standards

Science and Engineering Practices

- Developing and using models.
- Analyzing and interpreting data.
- Constructing explanations.
- Argument from evidence.

Crosscutting Concepts

- Cause and effect.
- Systems and system models.

Next Generation Science Standards

- Space systems (K-5, 6-8, 9-12).
- Gravitation and orbits (6-8, 9-12).

For the Educator

Facts you need to know

1. Earth's Moon is not the only moon in the solar system. Small planets in the inner solar system have two at most, but the giant jovian worlds in the outer solar system have dozens! Jupiter and Saturn both have more than 60 moons, from huge satellites larger than Mercury, to tiny irregular asteroids just a few miles across.
2. The ***Galilean moons*** of Jupiter were a key piece of data that pointed the way to proving the Copernican heliocentric model of the solar system was correct. These were almost the first discovery that Galileo made with his new invention – the astronomical telescope!
3. The Galilean moons are not simple barren rocks, they are complex worlds with volcanoes, oceans trapped beneath giant ice sheets, complex chemistry, and possibly even life.

Teaching and Pedagogy

The whole point of this model is to allow students to see what Galileo did when he first turned his telescope on Jupiter in 1609. Some of this is difficult for children, we have been brought up learning that *moons go around planets* – Galileo had no such advantage! When we teach a lesson such as this one, sometimes it helps children to role play and take on the roles of Galileo and some of his opponents for the day.

In his day, Galileo was taught that ***everything went around the Earth***. The core point of this exercise is to ask students ***to use what they see*** as experimental data and compare it to the predictions made by the ***geocentric model***.

Galileo originally thought that these bright objects near Jupiter were stars, but just a few days' observations convinced him that this could not be true. If Jupiter were moving through space, it would simply pass the stars by, ***but the stars themselves would not move***. These objects were clearly dancing attendance on the giant planet, and it did not take many days before Galileo realized that they were actually ***moons in orbit***. The interesting part was that the old geocentric theory said that "everything circles the Earth" – these new moons clearly did not do that.

Galileo named the new moons individually for lovers and friends of Jupiter (you may know him as Zeus!). He wrote to his employer, Cosimo de Medici about what he had found and said: "I have named this discovery for you – they are the ***MedicianMoons!***" History disagreed with Galileo, and today we know them as the ***Galilean Moons of Jupiter***.

Here again, we have a situation where new scientific data conflicts with an existing theory. The geocentric theory of Aristotle and Ptolemy had been around for almost 2,000 years and was as well accepted as any idea you can think of. Galileo challenging this idea was not well received – he was eventually put on trial for speaking against Aristotle's theory and teaching that Copernicus was right!

The popular resistance to Galileo's ideas didn't matter. The fact that 99.9% of scientists of his day ***believed*** in the geocentric theory didn't matter. ***Science is not about belief, it is about data and evidence.***

Galileo's scientific evidence, gathered with the telescope he invented, was very convincing. Galileo eventually wrote a book of do-it-yourself experiments and projects people could try at home to convince them that Aristotle's theory was wrong and needed to be thrown out in favor of the Copernican, sun-centered system.

Your students should be able to see easily that the moons orbit the planet Jupiter. Ask them: "How do we know this? What evidence is in our drawings that these are moons and ***not stars?***" The answer of course, is that the moons of Jupiter never wander far from the planet. Jupiter might pass by a background star and move on, but it would not drag that star along with it!

Student Outcomes

What will the student discover?

1. Like the Earth-Moon system, all of the planets and moons in our solar system operate on the same principles. Gravitation, the force we feel that binds us to the planet's surface, keeps all the planets and moons in orbit. The motions of planets and moons in space and the geometry between the planet, the Sun, and the observer controls what phases of the Moon we can see.
2. Our scientific models are usually constructed using incomplete data. Galileo could not observe the moons of Jupiter consistently 24 hours a day, and our students are not allowed to see the model all the time, either. Never the less, a useful model can be constructed!
3. Although it seems difficult, even impossible at first, we can discover the relative distances of the Galilean moons from Jupiter by looking at how rapidly their positions change!

What will your students learn about science?

1. Galileo's struggle to prove the Copernican model of the solar system correct is one of the most moving and profound examples of science in action we know. Your students will discover that it is ***scientific data*** that settles questions when two competing theories are present. Emotions, beliefs, traditions, or political power have no ability to influence the march of science toward the truth.
2. The evidence we see in the night sky must fit neatly into our scientific theories and models. If the data does not fit, we must adjust our theories – **not the data!** Galileo's dispute with the political and religious powers of his day boiled down to precisely this principle – and Galileo was willing to risk prison and death to stand up for the truth rather than change his data or support a model he knew to be incorrect.

Conducting the Activity

Materials

1. One, 5-inch Styrofoam ball
2. Four, 1-inch Styrofoam balls
3. 4 pieces of craft or piano wire, 24-inches long each
4. Wire cutters and pliers
5. The barrel of a plastic stick pen, cut in half.
6. An 8-inch square of cardboard or foam core board
7. Hot glue, markers, paints, etc.

Building the Jovian Moon Model:

1. Use markers or paints to decorate the large ball as a model of Jupiter. There are plenty of photo references on the internet for this, but don't worry about getting too fancy, the decoration will not be critical for our activity.
2. The smaller balls can be colored if you wish. If you are a stickler for accuracy, use orange/red for the innermost moon (Io), yellow for the 2nd moon (Europa), silver/grey for the two outer moons (Ganymede and Calisto.)
3. Use pliers to make a 90-degree bend in each of the wires about 2-3 inches from one end. Make a second 90-degree bend in each wire so that you have a squared off U-shape. Each U-shape should be wider than the previous on by a few inches so that the four little moons will be at different distances from Jupiter. Look at the figure below to get a better idea of what the finished wires should look like.
4. Trim both ends of the wires so that they are all the same length and push the small Styrofoam moons onto the wires. You may wish to secure them with a drop of glue.
5. Carefully push the plastic barrel of the stick pen into the North Pole of your Jupiter model until it is flush. Now use some hot glue to secure the South Pole of Jupiter to your cardboard base.
6. Put the wires with the little moons on them into the plastic barrel of the stick pen. This should hold them in place and allow them to rotate freely in 'orbit' around Jupiter. If they are a bit loose or wobble on their own, try putting a small ball of poster putty into the barrel of the pen to hold them in place while students observe them.

Exploring the Jovian Moon Model

1. Place the model across the classroom and set the four moons so that there are two on each side of your Jupiter model. The students will be playing ***Galileo*** and doing what he did! Have the students draw what they see – just a circle for Jupiter and a small dot or star for each moon is enough. They will be making several of these observations – they can draw each one or you can give them a worksheet as shown below.
2. Now have the students close their eyes briefly while you adjust the model. Closing their eyes represents one day passing for Galileo (he could not observer Jupiter during the daylight hours!).

> **[Teacher]** All the moons should orbit anti-clockwise. The inner moons move closer than the outer ones. Advance each moon as follows:
>
> **Io:** The innermost moon advances ½ orbit each day.
>
> **Europa:** The second moon out advances 1/3 orbit each day.
>
> **Ganymede:** The third moon advances 45-degrees each day.
>
> **Calisto:** The outermost moon advances about 20-degrees each day – about 1/8th of a circle.

3. When the moons have been adjusted, have the students open their eyes and draw what they see again. Remind them that this is 'day 2' of their Jupiter observation!

4. Continue moving and adjusting the moons for 5-6 days, then have the students look at their data.

Discussion Questions

1. How did you know that the moons were orbiting Jupiter and not just nearby stars?
   - **Answer** This very question was asked of Galileo! He was able to show that each of the moons had a particular distance from Jupiter (the size of its orbit), and that each moon had a particular orbital period (the time it took to circle Jupiter). The moons also never left Jupiter, they continually stayed near the giant planet – no stars would do this. These points together were conclusive!
2. How did this discovery challenge Aristotle's ***geocentric theory?***
   - **Answer** Aristotle's theory stated that all objects in space must orbit the Earth. Obviously the newly discovered moons orbiting Jupiter did not do this! Some scientists said Aristotle's theory only needed to be modified to allow other planets to have moons. As we shall soon see – this was not sufficient to save the old theory!

Supplemental Materials

Going Deeper

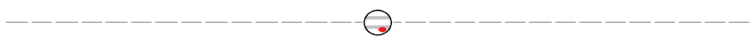
Galileo, Herschel, Huygens, Cassini, Hall and others discovered moons of planets by studying these planets carefully with telescopes here on Earth – but most moons are not discovered that way anymore!

Space agencies such as NASA (United States), ESA (European Union), JAXA (Japan) and others send spacecraft and telescopes into space and take high resolution photographs of planets. Independent scientists poor over many thousands of photos looking for specks of light that may be a new moon. Most of Jupiter's 67 moons were discovered by the Voyager and Galileo spacecraft. Similarly, most of Saturn's 62 moons were discovered by the Voyager and Cassini spacecraft – and many more will probably be discovered in years to come by scientists combing through the photos and data sent back to Earth by these robotic spacecraft.

Being an Astronomer

Today we know of more than 65 moons orbiting Jupiter, but the four large Galilean Moons still fascinate observers. As Galileo found, these large moons are easy to see, even with the smallest telescope.

You can observe and draw the positions of the moons of Jupiter easily enough. Try using this simple chart to guide you:



When you look at Jupiter in a small telescope or even a pair of good binoculars (8x or higher), you will be able to see the Galilean Moons. Use this chart to record the position of each moon that you see.

There are a variety of websites and software that will show you the position of Jupiter's moons on any given day. ***Sky and Telescope.com*** has one – search for *A Jupiter Almanac* on their website and you will find it easily. The ***Stellarium*** sky simulator software is also helpful, this is free software available at ***stellarium.org.***

Being a Scientist

Scientists have found that the large Galilean moons of Jupiter are worlds in their own right. Three of the four moons are larger than our own Moon, giant Ganymede is almost as large as Mars!

Each of these Jovian moons has a unique structure, and dynamic surface features that rival anything you would find on Earth! See what you can find out about them on the internet. From giant volcanoes on Io, to ocean geysers on Europa, and frozen craters on Ganymede – there are many things to explore. Which moon is your favorite?

Following Up

The Galilean Moon Europa is very unique. Exploration of this moon by the Galileo Spacecraft has discovered that Europa is an ocean world about the same size as our Moon. We didn't see this ocean world for what it was at first, because the entire ocean on Europa is covered in ice. It was only later experiments and observations by the Galileo spacecraft that confirmed that the oceans on Europa were many miles deep.

One of the things we know about the Earth is that wherever there is water, there is life. Every ocean, lake, and stream is inhabited with many forms of life. Even extreme water environments such as boiling pools in Yellowstone Park and lakes a mile beneath the ice in Antarctica have life in them.

What about Europa? So far, no one has found samples of life beyond the Earth; could Europa be the first place? How would you design a probe to look get through the ice and look for life in Europa's oceans?
