11.1: The Elliptical Model of the Seasons

This model predicts that the elliptical planetary orbits discovered by ***Johannes Kepler*** are indeed the cause of the seasonal changes. In this model, the Earth's axis stands perpendicular to its path in orbit, and the change in distance from the Earth to the Sun causes the change in the weather of the seasons as we move through the year. Our ping-pong models of the Earth, Moon, and Sun from Activity #23 are built on this premise. We've built our model with the Earth's South Pole glued to the poker-chip base, and the North Pole stands straight up. The Earth's axis is ***not tilted*** in this model. This activity works best with students working in groups of 2-3.

Academic Standards

Science and Engineering Practices

- Developing and using models.
- Planning and carrying out investigations.
- Analyzing and interpreting data.
- Constructing explanations.
- Argument from evidence.

Crosscutting Concepts

- Patterns in nature.
- Cause and effect.
- Systems and system models.
- Energy flows, cycles, and conservation.
- Stability and change.

Next Generation Science Standards

- Space systems (K-5, 6-8, 9-12).
- Waves and electromagnetic radiation (6-8, 9-12).
- The Earth-Moon system (6-8, 9-12).
- Gravitation and orbits (6-8, 9-12).

For the Educator

Facts you need to know

1. Every planet's orbit is ***elliptical*** in shape, rather like an oval, and the Sun is not located at the center. This means that every moon and planet is sometimes closer, sometimes farther away from the object they are orbiting.
2. The Earth's axis is tilted by about 23 degrees, but that axis stays pointing at the same point in space throughout the year as the Earth orbits the Sun. From mid-summer to mid-winter, the change in the tilt of the Earth relative to the Sun is 47 degrees.
3. Changes in the amount of solar energy we receive from the Sun cause the change in the seasons. When we receive more solar energy, we have spring and summer; when we receive less, we have fall and winter.

Teaching and Pedagogy

While working with this model, students will almost immediately notice that the Earth gets much closer to the Sun at some times of year, and many will quickly make the connection between winter and summer and the distance between the Earth and the Sun. As you discuss this, ask the students to mark the orbit to indicate Spring, Summer, Autumn, and Winter.

Marking the orbit in your model this way constitutes an ***hypothesis***, but is it correct? On the positive side, we see that our model indicates that we should have the seasons, and they are in the correct order! Having our model match what we already know to be true is an important step in accepting it scientifically!

In science, when we make a model or hypothesis, we must investigate further to determine what predictions that our model makes. If our model hypothesis is a valid one, it should ***make predictions***, tell us things we do not know or have not yet tested. These predictions allow us to design experiments to see if our model continues to be valid. The answers the experiments give us indicate whether we should keep this particular model – or throw it out as unsatisfactory.

Now it is time to go back to our model with another piece of string. Start with your model in the summer position (Earth closest to the Sun.) Stretch a piece of string from the equator of the Earth to the center of the Sun, and note the angle; this represents the angle of the Sun above the horizon at noon. Continue to move the Earth around its orbit and try again with the string, your students will quickly notice that the angle never changes – ask them why they think this is true? It won't take long for someone to note that the angle never changes ***because the Earth's axis is not tilted.***

This is the prediction we have been waiting for! Write this prediction down and put it up on your white board or on your wall somewhere. This is important! Your students have just taken the first steps down new roads by formulating predictions based upon a scientific model! This is what the adult scientists do in laboratories and in the field the world over. ***This*** is science – and your students are doing it! In our next activity, we will build and test the ***tilted Earth*** model and see what predictions it makes!

Student Outcomes

What will the student discover?

1. There are competing models for everything, the causes of the change of the seasons is no different. Your students will see two models for the change from summer's heat to winter's cold; the elliptical model where the Earth moves closer to the Sun in summer and farther away in winter, and the tilted axis model where the tilt of the Earth's axis causes the angle of sunlight to change from summer (more direct) to winter (more oblique).
2. One of the least appreciated concepts in science is that competing models or theories make different predictions. We've touched before on the idea that theories make predictions and show us where to look for new knowledge, but we haven't seen specifically how that idea is used to help us decide which theory is correct – and which theory we should discard.
3. The Sun's changing path through the sky as we proceed through the seasons of the year is caused by the tilted axis of the Earth. This might seem like a slow and ponderous movement that would be all but untraceable with simple equipment in the classroom. In fact, your students will discover that they *can* track the movement of the Sun across the sky, and its changing path from week to week.

What will your students learn about science?

1. Predictions in science are not a matter of guesswork, they arise from the testing and experimentation that we do with scientific models. Sometimes these predictions are a surprise to us, they emerge spontaneously as we work with a model. Other times, we suspect that we know how a model will function after we are finished building it. When the model confirms our intuition, then we proceed to verify these predictions with independent experiments.
2. It is the process of theorize, predict, experiment, and confirm (or reject!) that allows science to progress methodically. A scientist isn't predicting experimental results the way a gambler chooses a winning horse in a derby race! An hypothesis is never an ***educated guess!*** Scientific models create predictions as they function, we test these predictions with experiments.
3. For instance, we have seen that only one side of the Moon ever faces the Earth. If you play with your ping-pong models and look at the Earth from the Moon's perspective, you would see that the Earth would never move in the lunar sky. Our *model predicts* that for someone standing on the Moon, the Earth would never move across the sky, but remain spinning in just one place. This was a hypothesis, but there was no guesswork involved! And the Apollo astronauts confirmed this hypothesis in six trips to the lunar surface!

Conducting the Activity

Materials

1. Enough string to make a 16-inch long loop.
2. Two unsharpened pencils with fresh erasers
3. One ping-pong Earth model and one ping-pong Sun model (See Activity #23)
4. Construction paper (light colors work best)
5. Markers, rulers, pencils, tape, etc.

Building the Elliptical Model of the Seasons

1. Fold your construction paper in half the long way, and again the short way. This will mark the center of the paper for you.
2. Place the paper on the desk top and tape it in place at the corners.
3. Use a ruler and measuring out from the center on the long axis, mark two points, each 2-inches from the center. These points will be the ***focal points*** of our elliptical orbit. Mark these points carefully with a marker.

4. Have one student hold the two pencils, erasers down, on the focal points with the loop of string around them.
5. The second student puts a pencil inside the loop, and keeping the loop taught, they will draw an ***ellipse*** on the construction paper. If the ends of the ellipse do not meet perfectly, that is okay, have the students sketch over the pencil with marker and smooth out the discrepancies. Younger students may need some help with this (some of my high school and college students did!), but everyone should soon get the hang of it.

Exploring the Elliptical Model of the Seasons

1. The drawn ellipse represents the Earth's orbit. Put the Earth model on its orbital path and put the Sun model on one of the focal points. Have the students move the Earth around the Sun in an anti-clockwise direction. Remind them that one orbit is the same as one year (and its seasons!) Ask the students to write down whatever they notice as they work with this model.
2. If younger students are having difficulty with imagining how the elliptical orbit affects the seasons, ask them to think about what happens when they stand closer to a fireplace or stove, and then they move farther away. The connection between distance and warmth will quickly become clear.
3. Another way to explore this model works well with a cell phone camera. Start with the Earth at ***perihelion,*** its closest point to the Sun when we would expect summer weather. Place the cell phone ***directly behind the Earth*** and snap a photo of your Sun model.
4. Try this again with the Earth at Fall, Winter, and Spring positions – always keeping the cell phone directly behind the Earth model when you photograph the Sun.
5. Review the four photos, what do you notice? Most students will notice that the Sun is closer in summer, farther away in winter – but what about the apparent size of the Sun? In a substantially elliptical orbit, the Sun would look noticeably larger in summer, likewise it would appear smaller in the winter. This is a ***prediction or hypothesis*** that our model makes. Ask the students to think about whether this is true or not. How could they test this prediction?

Discussion Questions

1. What did you notice about the position of the Earth in its orbit relative to the Sun?
   - **Answer:** The Earth comes substantially closer to the Sun at some times of year than at others in this model. This change in distance *would* account for the change in temperatures from summer to winter.
2. If the Earth came substantially closer to the Sun at some times of year, what would you expect to observer in the sky? (Use your model to make a prediction.)
   - **Answer:** If this puzzles your students, take a ball of any type and move it slowly closer, and then farther away from them. They should notice that the ball appears larger as it gets closer, and then smaller again as it moves away. Does this match what they see in the sky from summer to winter?
3. What did you notice about the angle between the equator and the Sun as your Earth model moved around its orbit?
   - **Answer:** The angle does not change at all. Again, this does not match what we see in our sky. Ask students to take a look at their solar clock/calendars – has the Sun remained at a constant angle all year?

Supplemental Materials

Going Deeper

Could we use photographs to prove or disprove the idea that the Sun appears larger in the sky in summer, and smaller in winter? Challenge the students to think about this before you begin exploring photos. What ideas do they have? What reasons do they have to back up their ideas?

Often, we educators are too quick to jump in and correct a student when they are on the wrong track. I don't believe that this is always helpful. Remember that we do not do science to prove we are right, but rather to become right! Allow students to flesh out their ideas and think about them. Guide them to test these ideas and see where their ideas lead.

In the case of using photos to prove or disprove our idea of the Sun changing size in the sky, we won't make much progress. Look at landscape photos, sunset photos, etc. You will find that the size of the Sun changes dramatically ***based upon the camera***. Things such as zoom lenses can make a big difference in how large the Sun or Moon appear.

Could we use a camera to prove or disprove our ideas? Yes, but scientists take great pains to insure that everything else is the same such as same camera, same lens, same zoom setting, same location, and having the Sun at the same position in the sky.

We do this so that any changes we might see in the size of the Sun in the sky are actually a change in the Sun – not in our camera or photo! This is called ***controlling and limiting the variables.*** It is one of the most important ideas in science!

Being an Astronomer

Did you build the solar clock and calendar from activity #1? If you did, and if you have kept adding data to your solar calendar through the school year, you will now be poised to make another discovery!

Our ***elliptical model*** of the seasons shows no tilt of the Earth's axis. We actually found that there should be no change in the angle between the Sun and the horizon at any time during the year. What would this mean for our solar calendar?

If there were no change in solar angle on our solar calendar. This means that the shadow should never be closer to or farther from the base of the gnomon stick. The most we would expect to see is the dots forming a horizontal line across the page.

Of course, if you have done this experiment, you will find that the dots representing the tip of the shadow are tracing out a figure-8, or ***analemma*** on the paper. Your patient recording of data several times per week has ***proved the Earth's axis must be tilted.***

We often find that this is true – the results from one experiment give us sudden and dramatic insights on a totally different theory or hypothesis!

Being a Scientist

We talked about using a camera to prove or disprove the idea that the Earth gets significantly close to the Sun in the summer than the winter. If you, or your students, have access to cell phones, let's start taking photos!

Recess or lunch time is ideal for this, find a place where everyone can stand and take a photo that will show the Sun in the sky relative to some trees or buildings. Be sure that your camera isn't using a zoom function!

Take a photo once or twice per week and save them. After 4-8 weeks, compare the photos one to another and look for changes in the Sun's size in the sky. Of course, you won't find any real change – and this data indicates that the elliptical model is false.

Following Up

Some students get frustrated with this activity: "Why are we studying something that is wrong!?" The answer, of course, is that we are not seriously studying the elliptical hypothesis of the seasons as much as we are studying the methodology of science itself.

If we always study what is correct, how will we ever know how to recognize an incorrect theory when we see one? How will we know how to proceed and how to recognize the signs that a theory is invalid?

Science is a ***self-correcting process***, and an essential part of that process involves what we do when we make an error. Far too many students (and adults!) have the impression that 'the science is settled'; that science is a collection of truths and facts that are not open to investigation and debate. It is also just as dangerous to see science as a collection of opinions, choices open to our individual taste or desire.

Science is none of these things. But students must see ***science in action*** to appreciate the process and culture of science for what it is.