4.1: The Earth Clock

The concept of time is intimately connected with astronomy, and more particularly with the spinning Earth. We divide the Earth into 24 time zones, it takes the Sun one hour to move across each one of these zones. The motion of the sundial's shadow around the gnomon gives is the 'clockwise' direction (turning to the right). This motion is also intimately related to the Earth's spinning motion on its axis.

In today's world of digital clocks and cell phones, the concept of a 24 hour day being related to the rotation of the Earth has become more remote. This activity will bring home to your very modern students that the old fashioned idea of the sundial and the spinning Earth are closely connected with the time we keep.

Academic Standards

Science and Engineering Practices

- Developing and using models.
- Constructing explanations.

Crosscutting Concepts

- Patterns in nature.
- Systems and system models.

Next Generation Science Standards

- Space systems (K-5, 6-8, 9-12).
- The Earth-Moon system (6-8, 9-12).For the Educator

Facts you need to know

1. The Earth is both our oldest, and one of the most accurate clocks, spinning each day in exactly 24 hours (86,400 seconds!)
2. ***Diurnal motion*** is the daily motion we see as the Sun and Moon rise in the east and cross the sky to set in the west. This is also ***apparent motion***, caused by the rapid spinning of the Earth on its axis – not by any actual movement of the Sun or Moon in space.
3. Unlike our Sun which rises consistently at about the same time each day, the Moon's rising and setting time changes, rising and setting by almost an hour later each day.
4. The time of moonrise and moonset are intimately tied to the Moon's orbital motion around the Earth.

Teaching and Pedagogy

The concept that the measurement of time is linked to the daily motion of the Sun across the sky is a very ancient one. The Sun and Moon are the brightest and most obvious things in our sky and their regular motions and changes make them a natural focus for time keeping. Civilizations around the world have universally developed solar and lunar calendars in their earliest pre-history.

More than 2,200 years ago, a Greek named ***Aristarchus of Samos*** came up with the first known ***heliocentric model of the solar system***. In a time when most educated people believed that the Sun revolved around the Earth every day, Aristarchus theorized that a spinning Earth and a stationary Sun would explain the same ***diurnal motion*** we see in the sky each day as the Sun rises, crosses the sky from east to west, and then sets again.

Most people see, but do not reflect upon the diurnal motions of the Sun and Moon. It is a difficult thing at first, to lift your perception from off the surface of the Earth and envision the motion of the Earth as it spins upon its axis and revolves in orbit around the Sun. The best thing about this activity is that it helps the student extend their perception and envision our world as a planet in orbit around a star.

When we teach these activities to our students, we must take care to help the student see the larger picture. When we help students see beyond the ball and string of the model and make a connection to our solar system and how it works, these changes in perception can be both effective and lasting.

Sometimes in science, we have ***competing theories*** that both try to explain the same thing. We can argue if we wish, but only time, and careful experiments, can settle the issue for good! For older students in 5th grade and up, you may wish to show both theories with your activity. First have the Sun orbit slowly around the Earth which stands still. From the point of view of our Earth observer, the Sun will still rise in the East and set in the West at the correct times each day. After that, do the activity as described above – the Earth observer will see the same motion of the Sun across the sky!

I do not recommend showing competing theories to younger students however, as it can promote misconceptions and be confusing to them!

Students Outcomes

What will the student discover?

1. There is more than one model which can explain why the Sun and Moon rise in the east and set in the west each day. Our experiments with our models will help us decide which theory is best!
2. A common misconception is that the Sun and Moon rise and set at about the same time every day (This is true for the Sun, but not the Moon!) Your students will learn that the Moon's rising and setting time are tied to the Moon's orbital motion and change in a predictable way.
3. Seeing the Moon in the early morning sky is a surprising event that many people find inexplicable. Your students will learn that the ***waxing moon*** is visible in the early evening, while the ***waning moon*** is visible in the early morning – and why this is true!

What will your students learn about science?

Sometimes in science, we have ***competing theories*** that both try to explain the same thing. We can argue if we wish, but only time, and careful experiments, can settle the issue for good! For older students in 5th grade and up, you may wish to show both theories with your activity. First have the Sun orbit slowly around the Earth which stands still. From the point of view of our Earth observer, the Sun will still rise in the East and set in the West at the correct times each day. After that, do the activity as described above – the Earth observer will see the same motion of the Sun across the sky!

I do not recommend showing competing theories to younger students however, as it can promote misconceptions and be confusing to them!

1. ***Competing theories*** sometimes exist in science, sometimes for hundreds of years before the issue is decided. Science has room for more than one idea at a time, and more than one explanation of what we see in nature. Only experiments and data can solve these dilemmas – arguing, or asking 'Which theory do you believe in?' is pointless.
2. Standing on a moving platform (the spinning Earth) can make it difficult to sort out what we see. The spinning Earth creates the ***apparent motion*** of the Sun and Moon crossing the sky each day (also called ***diurnal motion***). Only careful experiments with different scientific models can help us sort out apparent motion from the actual motion of the Sun and Moon in space!
3. The measurement of time is critical to all science. Although the spinning Earth and orbiting Moon made humanity's first clocks, they are by no means our last! Learning about measuring time and motion is a key scientific idea.

Conducting the Activity

Materials

1. A large (3-ft) piece of cardboard – a science fair poster board works well for this.
2. A set of irrigation flags
3. An old baseball cap (adjustable size works best.)
4. Wooden yardstick
5. A large ball to serve as the Sun
6. A yellow vinyl play ball is preferred, but a basketball or soccer ball may be used easily enough.
7. Several 2-ft pieces of rope or strong cord (clothesline cord works well)
8. Markers or paints
9. Construction paper – various colors (optional)
10. Hot glue gun

Building the Earth Clock Model

1. **[Teacher]** Begin by hot gluing the yardstick horizontally across the back of the large piece of cardboard. This keeps the cardboard ridged and makes it more durable. If you are using a folding piece of cardboard such as a science fair poster board, you can attach the yardsticks with Velcro. This will insure the cardboard piece is still foldable and stores more easily.
2. **[Teacher]** Using a screwdriver, punch two holes in the cardboard (one above the yardstick, one below) at each end of the yardstick. Thread a 2-ft piece of rope or cord through the holes and knot it securely on the yardstick side. Use hot glue to secure

the rope in place. This creates handle loops to help students hold onto the device.

3. Take two irrigation flags and mark them as ***East*** and ***West*** (you may also use index cards for this.) Use duct tape to attach them firmly to the back of the artificial horizon so the flag sticks up over the edge of the cardboard and is visible to everyone. When looking at the front (smooth side) of the artificial horizon, the East flag goes on the right side, while the West flag goes on the left side.
4. **[Optional]** Students can decorate the horizon by adding a skyline at the eastern and western edges. These can be drawn on poster board and then cut out and taped or glued in place. This allows the person using the horizon to see the Moon in relation to houses, mountains, etc.
5. Make a 'Time Hat' by cutting out a long arrow (12-15 inches long) from poster board and taping or gluing it to the top of the hat so that the arrow points straight out past the center of the bill of the hat.
6. Mark 12 irrigation flags as follows: 2 am, 4 am, 6 am, 8 am, 10 am, Noon, 2 pm, 4 pm, 6 pm, 8 pm, 10 pm, and Midnight. If you have different color flags, use one color for am and another color for pm. Alternatively, you can staple two different colors of construction paper to the flags and mark them that way. The flags work well in any grassy area.
7. Place an irrigation flag in the grass to mark the center of your clock face. Use a cord as a compass (the 7-ft cord from the Earth-Moon system model works well) and mark out a clock face on the ground using the labeled irrigation flags to show the hours. Remember that you are marking a **24-hour** clock, so instead of having 12, 3, 6, and 9 at the cardinal points like a standard clock face, you will have Noon, 6 pm, Midnight, and 6 am. Place the other hour markers appropriately.

Optional: If you do not have a large grassy area to work in, you can cut 4-inch long pieces of 2×4 lumber, drill small holes in them, and hot glue the flags in place. These inexpensive wooden stands will allow the flags to be placed on any floor or hard outdoor surface.

Exploring the Earth Clock Model

1. With your clock face marked out, half of the circle represents AM (daytime) and half of the circle represents PM (night time). Have a student hold the Sun ball at the Noon position. All is now ready!
2. The student playing Earth must hold the artificial horizon cardboard steadily across their shoulders (rather like a backpack!). The horizon limits their view to 180 degrees (just like the real horizon does) and prevents them from looking behind themselves (we cannot see 'behind' the planet, either!)
3. Begin standing facing the Sun, and the Noon flag. Whichever flag they are facing tells the time (they ***are*** the hour hand on our clock!) The first 'day' begins at noon with the Sun directly overhead!
4. The Earth student now spins slowly to the left (anti-clockwise) – this represents the Earth's ***daily rotation*** on its axis. As they turn slowly, they will see the Sun move slowly westward, and finally disappear over the western horizon! What time is it? The Earth clock will say approximately 6 pm. The student may object that they are moving, not the Sun – ***Exactly!***
5. Continuing to spin to the left, the student will see the Sun rise again over the eastern horizon – they will now be facing the 6 am flag – sunrise! Have each student spin through several days so that everyone gets the concept of the ***diurnal motion*** of the Sun – and understands that it is caused by the spinning motion of the Earth and that the Sun does not actually move at all!

Discussion Questions

1. How many hours are there in a day? Is this a natural number (based on some observation) or a human invention?
   - **Answer** There are 24 hours in the day, but this is purely a human invention. The Babylonians were the first society to divide a circle into 360 degrees, 24 divides neatly into 360, making the hours of reasonable length and easy to measure throughout the day.
2. Imagine that the Earth spun four times faster, spinning on its axis every six hours instead of a leisurely 24 hours. How would things be different for you on this fast-spinning planet?
   - **Answer:** This is a wonderful question for stimulating a child's imagination. In fact, our early Earth did spin 4-5 times faster than it does today, the Moon slowed Earth's rotation down over billions of years and continues to slow us down today!
3. What would the world be like if the Earth didn't spin at all?
   - **Answer:** This seems like a strange question, but it is a good lead in to ideas we will explore in further units and activities. Before 1600, most astronomers believed that the Earth did not spin and did not orbit the Sun. This idea, called the ***geocentric theory***, was developed by a Greek thinker named Aristotle almost 2,500 years ago. Aristotle proposed that the Earth was ***fixed***, or unmoving and was the center of the solar system

Supplemental Materials

Going Deeper

We are all familiar with the idea of the ***leap year***, when we add a day to the calendar every four years. We add this extra day because the Earth's orbit around the Sun takes **365.26** days. We have to deal with the extra quarter day by adding a day to our calendar every four years. In effect, we use the leap year to clean up messy fractions that wouldn't work in our calendar!

An interesting variation on this idea is the ***leap second.*** Like the leap year, this idea is used to clean up messy fractions. We say that the Earth's day is ***exactly 24 hours or 84,600 seconds***, but in fact this is not true! Like the Earth's rotation around the Sun, the Earth's spin on its axis does not match our clocks and calendars precisely.

Explore the idea of the leap second; search the internet and see what you find.

1. Is the Earth rotation time shorter or longer than 84,600 seconds? By how much?
2. Is there a regular schedule for adding a leap second? (Remember the leap year happens on a regular schedule every four years.)

Being an Astronomer

Timing the rising of the Sun or Moon can be a reasonable way to time the Earth's rotation! This works best when sunrise or moonrise is straight up off the horizon; for this reason you will get the most accurate results timing the sunrise in June, and the moonrise in December. All this requires is a stopwatch!

Position yourself to see the Sun or Moon rise over a flat edge – the edge of a building works well, students can watch the Sun come up over the roof of their own house on a clear morning!

Start timing when you can first see the edge of the Sun's disk, and stop when the disk is ***completely*** over the edge and clear of the building; this will take about two minutes. Remember that the Sun is blindingly bright – don't stare at the solar disk the whole time, just glance at it occasionally so you know when to stop your timer!

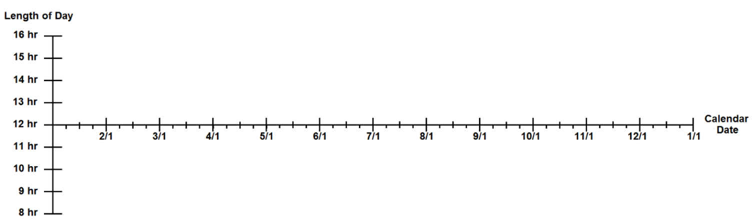
Take the time ***in seconds*** and multiply by 720[1]. The Earth's actual rotation period is 86,400 seconds (24 hours) – how close did you get?

Being a Scientist

When we think about what a day is, most people think about the time between sunrise and sunset. The problem is that the number of hours of daylight we have changes throughout the year, this is also part of our ***Earth Clock***.

An interesting investigation can be made by graphing the number of hours of daylight for every day of the year. Students can do this by using an app or website to tell them how many hours of daylight each day; or by using a weather website to find the time of sunrise and sunset and working out how many hours each day and then plotting the results on a daily graph.

The graph should look something like this:



Plot the length of the day in hours on the 1st, 7th, 14th, and 21st of each month. Over the length of the year you should see a beautiful curve formed by the points on your graph. 12 hours is used as the center point of the graph because that represents a day perfectly divided with equal hours of daylight and darkness. These days are called the ***equinoxes***; the name comes from the Latin language, meaning *equal night. S*ee how many equinox days you can find in a year.

There are also days when we have the longest and shortest day; these days are called ***solstices.*** The word solstice also comes from the Latin, meaning *Sun stands still.* Can you find the longest and shortest days of the year on the graph? How do these days relate to the seasons? How can we explain these slow and steady changes of daylight and darkness? We will explore these ideas further later in the book!

Following Up

Having a regular place in your classroom where you record days of the week or showing the month and date is fairly common in a classroom. These things help students develop their sense of time, seasons, weeks, semesters, etc. Consider adding some astronomical features to your daily calendar such as the phase of the Moon, the length of the day, or noting equinox and solstice days!
