

# **Science Design's Foucault Pendulum Lesson Plans for Grades 5-8 and 9-12**



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# **Lesson Plans for Grades 5-8**

## The Foucault Pendulum for Grades 5-8

### Learning Objectives:

Students will be able to discover some of the behavior of pendulums and the special behavior of Foucault pendulums. Students will be able to prove to themselves that the Earth rotates. The first part gives a background to pendulums while the second part explores the Foucault pendulum.

### Planning:

Time: Set-up: Approximately 5 minutes per pendulum.

Class time: 30 minutes

### Materials for each group of 2-5 students:

- Pendulum – could be a 25+ g mass on monofilament or thread hanging from a ring stand at least 40 cm above its base.
- Ruler
- Stopwatch
- Lab notebook or paper for noting questions, procedure, observations and conclusions

Note: monofilament can be tricky to tie. A useful site is the Trilene knot at

<http://www.animatedknots.com/trilene/index.php?LogoImage=LogoGrog.jpg#>

### Pre-lab Demonstration:

Discussing the parts of the pendulum and demonstrating way to set it swinging can avoid

#### Common Errors:

Students sometimes release the bob with an initial added acceleration. Or they release it from a position where the string is not fully extended (it is slack.)

Disturbing the pendulum's base (table) through jarring

**Assessment:** Each group to report one of the characteristics they discovered about pendulums to the rest of the class and to demonstrate its veracity with the data they collected.

### Multimedia Links & Further Exploration:

Pendulums <http://en.wikipedia.org/wiki/Pendulum>

Foucault pendulum [http://en.wikipedia.org/wiki/Foucault\\_pendulum](http://en.wikipedia.org/wiki/Foucault_pendulum)

The Foucault pendulum at the South Pole -

<http://www.phys-astro.sonoma.edu/people/students/baker/SouthPoleFoucault.html>

Robert Crease The Prism and the Pendulum, The Ten Most Beautiful Experiments in Science, 2003, p. 124-139

## Question: What do pendulums do?

### Key Vocabulary:

**Pendulum:** the whole system that has a string attached at one end, with a mass hanging freely from it and that can swing back and forth

**Bob:** the mass that swings at the bottom of the pendulum's string

**Pivot:** the place where the string of the pendulum is attached to its support

**Position:** where the bob is at any moment

**Amplitude:** how far the bob swings from hanging straight down

**String:** could be a rod or a stick

How do you know that the Earth is turning? This is one of the trickiest of the everyday ideas to discover. What evidence do you have that the sun is not going around the Earth? Copernicus and Galileo used some sophisticated observations of the stars to show that the Earth revolved around the sun in the mid 1400s.

A French man, Leon Foucault, was not satisfied with this explanation. He wanted to see evidence for himself that the Earth is turning. Leon was a college drop-out, not a professional scientist. What he did well was to make careful and patient observations and figure out how to make machines that help us see what our senses can not. He and a partner were the first to take photographs through a microscope. Next he figured out how to measure the speed of light and take good photographs of the sun and the stars. On January 3, 1851, he carefully set up a pendulum in the basement of his house and saw that the Earth was moving. We can see it too.

But wait! What exactly is a pendulum and how does it work? Some people think of a playground swing. Others remember a Grandfather clock, the long part swinging back and forth, ticking and tocking to measure out time. Any set-up where something is attached or fixed at one spot and where the other end can hang down and swing back and forth is a pendulum.

You can make a pendulum by hanging a shoelace from your finger and letting it swing. But if we want to observe what characteristics describe pendulums, we want to have a BIG mass hanging a long distance from the pivot on a string with which weighs nothing. In the real world, let's try a bob of at least 25 grams hanging on a string about 40 cm long.

**Materials for each group of 2-5 students:**

- Pendulum – could be a 25+ g mass on monofilament or thread hanging from a ring stand at least 40 cm above its base.
- Ruler
- Stopwatch
- Lab notebook or paper for noting questions, procedure, observations and conclusions

**Procedure & Observations**

1. What is the size of your pendulum? Measure the length of your string and note the mass of your bob.

**2. Swing period and amplitude**

Length of time for one swing (period). Measure 10 swings and divide that time by 10. What happens if you just let the system go? Do the periods get shorter, longer, stay the same? How far does it swing out from the pivot over the table? Is the distance on the other side bigger, smaller or the same? What happens if you just let the system go? Does it swing out farther from or shorter than or stay the same as the point where you released it?

3. Have different members of your group look at it from the top, from the front, from the side. Make a drawing or write a description of exactly what you observed. Share your observations with each other. Then make your own observations from the other positions.

4. What seems to affect the pendulum? What changes over time? Why do you think it does that? How can we test that idea? Can you affect your pendulum in a predicted way?

You may wish to try one of the following ideas:

Longer, shorter strings

Different masses of bobs

Change the initial amplitude

Environmental conditions – air currents, bumps and jars

Your own idea....

**Conclusions**

Monsieur Foucault had some trouble convincing some of the professional scientists in Paris that his pendulum showed the Earth moving. Communicating about your discoveries has been a necessary part of scientific work for a long time.

5. Share one of the discoveries you made in your group with the rest of the class. Can you show that what you say is true?

**Extensions**

Explore the trade-offs between potential and kinetic energy as the bob moves. Look for pendulums in the world around you. Which were designed to be pendulums and which act as pendulums even if that is not what they were for?

## Part 1: Characteristics of Pendulums

1. Length of string \_\_\_\_\_  
Mass of bob \_\_\_\_\_
2. Time for 10 swings \_\_\_\_\_ divide by 10 = time for 1 swing \_\_\_\_\_  
Observations about the period (time to swing)

Amplitude – distance out from center or the height above the height of the bob straight down.

Choose one and tell us why you chose it. \_\_\_\_\_  
Observations about amplitude

3. From the front:

From the side

From the top

4. Ideas about pendulums

What we decided to test and how.

Our observations:

5. Be prepared to show your discovery to the rest of the class and convince them about your observations. When scientists describe their conclusions to others, they often find they have more work to do. What more did you find that you need to investigate?

## Part 2: The Foucault Pendulum

### Planning:

Time: Set-up aside from the Foucault pendulum, 20 minutes

### Materials:

- Pendulum – could be a 25+ g mass on monofilament or thread hanging from a ring stand at least 40 cm above its base
- Possibly a rotating lab stool or lazy susan
- Globe or large ball
- Pipe cleaner shaped into a model pendulum and base with a semicircle attached to it to represent its plane of swing
- Tape to mount the pipe cleaner pendulum to the ball
- Foucault pendulum
- Stopwatch
- Lab notebook or paper for noting questions, procedure, observations and conclusions

Because there is likely to be only one Foucault pendulum in the class, use this lab as a collaborative lab and discussion. Today physicists still do the sort of “thought experiments” Einstein made famous. What we are calling the “plane of swing” is more correctly termed “the plane of oscillation.”

### Pre-lab Demonstration:

Start a pendulum swinging. Note what plane in which it is swinging relative to the room. Carefully rotate it, stopping every 45 or 90 degrees and noting its plane of swing. If turning the pendulum gently and evenly is difficult, use a smoothly rotating lab stool or a lazy susan to turn it gently. A pizza tin completely filled one layer deep with marbles can substitute for a lazy susan.

### Mid-lab demonstration:

The globe or large ball represents the Earth. The classroom is the “universe” and the pipe cleaner and semi-circle is our Foucault pendulum. The plane of swing will stay oriented in the same direction in the classroom “universe” as the ball turns. Have one student responsible for keeping it in its proper position as another rotates the ball. Tape the pipe cleaner pendulum on the globe in the approximate north-south position of your city. Stop frequently and observe how the plane of swing would look to someone standing on the ball. Have the students try the pendulum at “the North Pole” and close to but not on the “Equator.” Foucault showed that the plane of swing seems to rotate in proportion to the sine of your latitude.

### Assessment:

### Extensions:

Museums, banks and universities have different things under and around their pendulums. Sometimes maps, or artwork, sometimes sand which is marked by the bottom of the bob. Have your students decorate the floor beneath your pendulum.

## What is special about a Foucault pendulum?

Does the Earth rotate? How do we know? How does the pendulum show that? One of Newton's laws of physics says that something that is moving stays moving unless it gets pushed by another force. This is part of why pendulums keep swinging in the same direction even when we turn them. The pivot puts a force on the pendulum but so do air currents or vibrations in the floor when people walk by.

### Procedure:

1. Was the Foucault pendulum already swinging when you came into the room? When did it start and what direction in the room was the plane of swing when it started. Now note the direction of the plane of swing and what time it is. Then come back to reading.

**What is special about a Foucault pendulum?** Our little pendulums stop after a few minutes. Showing that the plane of swing is different than the plane of the room takes time. Leon Foucault's first pendulums had very massive bobs and carefully machined pivots that would not hold the string tightly in one position. He also made his pendulums big, really **big** so that people moving about, doors opening and shutting, and air moving around the room wouldn't matter much. It could keep swinging and swinging, hour after hour. Slowly, hour by hour, it seems to move in a circle. Or in truth, the Earth moved under it.

Great mass, long strings, freely pivoting meant that there were long periods and little friction. Most of the museums and other places with Foucault pendulums today have a space taller than the gym. The one at Fermilab in Illinois is 16 stories high. Bobs with a mass over half a ton are common. Our Foucault pendulum has a little bit of a push added to it, just like the push you give to a swing when you pump your legs when swinging to keep going.

2. Check the plane of swing again. How much time has passed? Could you see any change? Hmm, what does that mean?

Monsieur Foucault was very, very good at geometry and could picture what was going on in his head. We have a model to help us see. In our model, the room is the universe. Our globe or ball rotates as each day passes while our pendulum model swings away.

3. What is the plane of swing as we start? As the globe rotates, the plane of swing stays in the same direction in the universe. Stop the globe. Where is the plane of swing? How would it look to someone standing on the globe? Rotate a bit more, and more and more until the globe is back in the position it was in when you started. Wait a minute. What does the observer see? Does it look as if the plane of swing has made a complete circle?

Meanwhile

4. Check the plane of swing again. How much time has passed? Could you see any change?

Monsieur Foucault figured this out too. Where on the Earth do you think the pendulum will seem to turn in a circle in 24 hours? Where will it take longer? Try out these ideas by moving

your pipe cleaner pendulum. What happens? What do you think this means for your Foucault pendulum?

### **Conclusions**

5. Check the Foucault pendulum once again. How many degrees has it changed? How long did it take to change that many degrees? Divide the degrees by the time in minutes. That is your speed of rotation in degrees per minute. If you divide 360 degrees by your speed of rotation, you will get how long it will take to make a complete circle.

$$t = 360 / r$$

where t is time and r is the rate (speed) of rotation.

If you can keep the pendulum from being disturbed, see if your calculation is the same as the experimental time.

Did we see the Earth turning? Did we show that the Earth is rotating? Are you convinced?

# **Lesson Plans for Grades 9-12**

## The Foucault Pendulum for Grades 9-12

1. The Pendulum: simple and driven
2. The Foucault pendulum plane of oscillation rotates.
3. Sundials and the Earth's rotation
4. Assessment

### Does the Earth move or is the Earth fixed? Spinning Earth Model versus Fixed Earth Model Notes for the Teacher

#### 1) Why can't we tell if the Earth is fixed or rotating?

How can we look at something that is so familiar that it is a surprise that a question exists at all. How do we know that the Earth is turning?

Every day the Sun rises in the East, travels across the sky and sets in the West. The Moon and the stars also rise in the East and travel west. The Moon goes a little slower. If the Moon starts out in the East at sunset on one day, then a day later it rises about an hour after sunset; each day brings another hour delay. It's as though the Sun goes faster because it is more important. The stars also move across the sky, but their rate differs from both the Sun and the Moon. It takes a long time to notice, but after about two weeks, the stars rise about an hour earlier. This amounts to an advance of about one degree per day. The facts that there are 365 days in a year, and that 360 is divisible by many integers are some of the reasons that we have 360 degrees in a circle.

Ancient astronomers kept track of the stars' movements by noticing which constellation was on the eastern horizon just at dawn. They identified 12 constellations which rose with the dawn; each at its own time of year. The constellation that is on the eastern horizon on the first day of spring determines the star age. In historical memory, this "spring" constellation has changed from Taurus the bull to Aries the ram to Pisces the fish to Aquarius the water carrier. It takes about 2500 years to change from one star age to the next.

The fixed Earth model just describes what we see. The Sun, Moon, and stars move through the heavens at their own rates, independent of each other.

The early astronomers noticed a coincidence that suggested a spinning Earth model. Our seasons are determined by the Sun; it is high in the sky during summer and low during winter. Yet there also seems to be a connection between the seasons and the stars. In the course of a lifetime, the "spring" constellation is always the same. The spinning Earth model describes a connection between our observations of the sun and our observations of the stars. We suppose that the stars are always in the heavens, but during the day, the sun is so bright that we cannot see them.

## 2) The Models

**The fixed Earth model** is straight forward. The heavenly bodies circle around the fixed Earth, each body traveling at its own rate. The Moon falls behind the Sun in this daily race across the sky, and the stars inch ahead a little each day. The planets wander on their own paths. Summer is caused by the Sun rising higher in the sky during the day. The progress of the constellations, in which we always see the same stars in the summer, is deemed a coincidence; nothing more.

**The spinning Earth model** is more complex. The Earth is not only in motion, but it has two distinct motions. First, the Earth orbits around the Sun once per year. This revolution explains the connection between the stars and the yearly seasons. Every year in the same season, the same stars are obscured by the Sun during the day, and the same stars are seen during the night.

Second, the Earth spins on its axis once per day. This rotation is seen as the Sun rises and sets each day. We think of the Sun as being fixed in place, and conclude that the Earth spins us so that we alternately see the Sun in the daytime and face away from it at night and see the darkness of space, punctuated by the stars.

Third, the Moon orbits the Earth at its own rate. We see it rise and set because the Earth spins. It travels from west to east in its orbit (just as our communication satellites do) so that it rises later each day. The fact that we see 13 full moons per year is a coincidence. (It may be because 13 moons per year were important in pre-Christian religions that this is the reason for that led to 13 being a modern-day “unlucky number.”)

## 3) The Resolution

For centuries, both models successfully described the behavior of the heavens. The choice between them was essentially a political choice, made with insufficient information to be certain of the answer. Scientists in the 1500s found a mathematical explanation of the Sun-centered, spinning Earth model that made a simpler, more straight-forward description. Religious and political bodies preferred the fixed Earth model as one where the Earth is the center of the Universe, its most important member. Galileo stood trial and suffered house arrest when he advocated a spinning Earth.

Recently released documents show that Galileo’s inquisitors would have been willing to accept the spinning Earth model if there were any evidence that it was correct. Galileo could not produce the evidence. The astronomical evidence could be interpreted either way. The best he could do was to show that the spinning Earth model was not wrong and demonstrate the mathematics for both systems.

Foucault’s pendulum finally gave physical evidence of the spinning Earth model. The plane of oscillation, the plane in which the string and bob move, remains unchanged or fixed in space as the Earth rotates under the pendulum. The rotation of the plane of oscillation is most simply described by the spinning Earth model.

## Foucault Pendulum Vocabulary

**Pendulum** A system comprised of an overhead support from which a *string* hangs, and an object or *bob* is suspended at the bottom end of the string. The object swings back and forth under the combined influence of gravity and the string.

**Pendulum Bob** Any object that hangs on the pendulum string. It can be a toy, a bowling ball, or a small car if the string is strong enough. Its vertical position bobs up and down while its horizontal motion moves side to side.

**Pendulum Pivot** The pendulum string is attached to the overhead support by the pivot. The pivot might simply be a knot that ties the string to a hook in the ceiling. For a Foucault pendulum, great care is taken that the pivot allows the pendulum to swing with the same ease in all directions of the compass.

**Position** A reference point or origin described by a picture, with words, or with equations. Positions tell two things: the distance from the origin, and the direction that you have to go in order to move from the origin to the object. The distance is measured in length units such as meters. The direction can be described by stating an angle between the line from origin to object and a reference direction, such as East.

**Oscillate** The back and forth motion of a pendulum's bob and string. Its position is said to oscillate back and forth.

**Period** The amount of time it takes the bob to make one round trip. If the pendulum bob is pulled back and released, it returns to the hand that released it after a time interval equal to one period. The period of a 1 meter long pendulum is 2 seconds.

**Amplitude** The maximum displacement of the bob from its equilibrium position. When the pendulum is at rest, not swinging, it hangs straight down in the *equilibrium* position. This position is usually defined as the reference position or origin. The position of the pendulum varies to the left and to the right of the origin. The size of the largest distance away from the origin is called the amplitude. The bob swings to a distance equal to the amplitude on the left and next swings to a distance equal to the amplitude on the right.

**Plane of Oscillation** If the bob is pulled back and released from rest, the path of the bob lies along the plane defined by the string and gravity. This path lies in the plane of oscillation. Because the string and gravity lie in the plane, we expect that the plane of oscillation will never change. The surprise of the Foucault pendulum is that the plane of oscillation changes direction, clockwise in the northern hemisphere, as the day goes by.

**Rotation** If the position of an object changes along a circular path, the object is said to rotate along that circle. The second hand of an analog clock rotates clockwise. The plane of oscillation of a Foucault pendulum rotates clockwise in the northern hemisphere.

## Lesson 1: The Pendulum: Simple and Driven

What is a pendulum? Why would you want to drive it and how do you build a driven pendulum?

**Learning Objective** – Construct your own simple pendulums and be able to explain what is necessary to build a driven pendulum.

### Part 1: A simple pendulum

#### Materials for each team

2-5 washers  
a paper clip  
pieces of string 20 cm, 40 cm & 80 cm long  
masking tape  
ruler  
protractor  
stopwatch

#### Procedure:

##### Part A. A simple pendulum

1. Your team has the essential items to construct a simple pendulum suspended from an object in this room. Take 2 minutes to assemble a pendulum.
2. How would you describe its properties and behavior to those who could not see it? List the details of your observations during the next five minutes.
3. How long did it continue to oscillate back and forth? What happens if you vary the length of the string? What happens if you add mass to the bob? What variables seem to be associated with the period? What slowed it down?

##### Part B. Driving a pendulum

4. Brainstorm ways to keep the pendulum going for a longer time.
5. Describe in words or in pictures how you pump a swing. Where do you add energy if you are pushing someone on the swing? How does that differ or stay the same if you are the person pumping your legs on the swing?
6. Another way to keep the pendulum swinging is to add energy by pulling up and dropping the pivot. The room-sized Foucault pendulum uses a speaker diaphragm to do this. At what point does the speaker pull up and at what point does it drop down?

**Extension:**

Label each simple pendulum set up with a letter. Randomly assign a number to each of the descriptions and keep a copy of the key as to which letter matches each number. Distribute the descriptions to the different teams and ask them to find the pendulum which it describes. The time it takes for each team to find the described pendulum is part of their score. Add to it the time it took for another team to find the pendulum which they had described.

**Teacher Notes:** The fact that the driven Foucault pendulum does not behave like others suggests that an unspoken assumption has been violated. In this case, the speaker is replacing the energy that is removed by friction of the string with its pivot and the string and bob with air currents. The pumping a swing problem is explored more fully in the classic Mechanics (Course of Theoretical Physics) by E. M. Lifshitz and L. D. Landau, Third Edition c1982.

Answer to 6. pull up at the bottom of the swing; drop down at the top.

## Lesson 2: The Foucault Pendulum - The Plane of Oscillation Rotates

Imagine what happens to a pendulum as it is turned in a circle. How would your observations of the pendulum's behavior differ from observations of the Earth turning under the pendulum?

**Learning Objective** - Relate the rotation of the plane of oscillation of the pendulum to the spin of the Earth.

The ordinary motion of a pendulum is in a plane. Back and forth, to and fro, the bob swings straight in a plane defined by the string, the plane of oscillation. The string and gravity both exert forces on the bob. The direction of this plane of motion will not change unless another force pushes or pulls sideways on the string or bob.

There is a wrinkle. If we inadvertently nudge the bob, putting a force perpendicular to the plane of oscillation, the bob traces out an elliptical path. The pivot's structure can also induce a twist or pull in the string. Leon Foucault took incredible pains to design a pivot that could allow the string to swing freely. His second problem was that the initial start of the pendulum could add a perpendicular component to the pendulum's path. His solution was to take the bob out to full amplitude and tie it with a thread, then burn the thread with a candle. Foucault's invitation to the Academie des Sciences to a demonstration of his pendulum read:

*"You are invited to see the Earth turn..."*

All motion is relative. We detect the motion of one object by comparing it to another object. In the case of the Foucault pendulum, the other object is the room the pendulum is in. Newton thought about the centrifugal force that makes water pile up on the sides of a spinning bucket. The piled-up water is evidence that the bucket is "really" spinning. We can see the same thing when a salad spinner throws the greens towards its outside wall or the spin cycle on a washing machine leaves the clothes around its wall. You can tell that they are in motion with respect to the fixed stars, but the motion is still relative. The spin of the Earth is a more subtle thing, but the Foucault pendulum gives us a chance to see it.

### Materials

Foucault pendulum  
Clock or watch or timer to measure elapsed time  
Clock face or 360° compass rose  
Calculator

### Procedure:

#### **Part A. The plane of oscillation rotates**

1. Read and record the measurements from the clock-face at the base of the pendulum; note the time and the plane of oscillation (direction of swing.) You may wish to make a mark on the floor with chalk, masking tape or washable markers at the two spots where the bob reaches its maximum amplitude. Take readings every 20 or 30 minutes throughout the day. You can describe the plane of oscillation as a compass direction such as North or North/South or as the path it takes such as 180/360°.

Date	Time	Direction of swing	Amplitude (greatest size of swing)	Period (time for one round trip)
October 25	10:30 am	East Northeast or 73°	20cm	6 seconds
October 25	12:30 pm	East/West or 90°	19 cm	6 seconds
October 25	1:30 pm	East or 90°/270°	18 cm	6 seconds
October 25	2:30 pm	ESE/WNW or 113°	20 cm	6 seconds

2. Walk around the pendulum; stop every 45° and describe or draw what you see. How do your observations change or stay the same as you move? Draw or describe what you would see at the level of the bob? What would you see if you were hanging from the ceiling looking down at the pendulum?

### Part B. Relative Motion

The pendulum has remained in motion since earlier in the hour. The log likely shows that it is now swinging in a different direction. Could you observe any changes in the motion of the pendulum? Discuss with a partner what you changes and constants you have observed and then hypothesize as to why the changes took place. If you detect a direction change, how can we determine that someone did not bump it? What other reasons could have caused the change in motion?

Take a piece of paper and crease the paper lengthwise. Label the first column “pendulum moving”, and the second column “we are moving”. Record any evidence that can help decide if it is the pendulum moving or are we moving. What tests could you devise to help you determine this?

### Part C. Calculating the Rate of Rotation

The next day:

How many degrees did the plane of oscillation turn during the time it was observed? How long a time did that take? How many degrees does it turn in an hour? How long will it take to rotate a full 360°?

Leon Foucault calculated that the time would be related to the latitude of the pendulum’s location.

$$t = 24 / \sin(\text{Latitude})$$

where t is the time it takes the pendulum to turn 360°.

What is your latitude? Calculate the time to turn 24 hours. How does that compare to your experimental results?

### Conclusion:

What evidence can you give to prove which is “really moving” in a circle, you or the pendulum?

**Extension: Foucault Pendulum at the North Pole**

What would happen to the pendulum if it were swinging at the North Pole? Would your explanations be the same if the Earth were fixed?

**Teacher Notes:** If it is not possible to leave the pendulum running, start it as soon as possible, in the same direction as it ended in the previous class. Make calculations using only the time spent swinging.

### Lesson 3: The Movement of the Sun or the Earth

Can we tell from the movement of the sun if the Earth is fixed Earth or spinning? What direction did the shadow on the sun dial move?

The shadow cast by a sundial tracks the apparent motion of the Sun. The pointer (gnomon) interrupts the light and casts a shadow. The line from the shadow to the gnomon tells us the direction of the path that the light followed from the Sun to the sundial.

**Learning Objective** – Understand how the fixed Earth/moving Sun model persisted alongside a moving Earth model.

#### Materials

Sundial

Scissors

Flashlight for every 5 students

Watch or clock

#### Procedure:

1. Build your sundial (see next page)
  - A. Cut along the solid lines.
  - B. Fold the “tongue” up vertically at the dotted line.
  - C. The sun from the south will cast a shadow towards the north. Mark the location of the shadow at various times. Write the time at that mark as well.

#### **Part A. Tracking the Sun**

2. Find a spot with a view of the sun near the window in the classroom or go outside with the class.
3. Lay the sundial on the ground and look at how the Sun’s shadow is cast on the paper. The Sun’s light is traveling in a straight line from the sun to the dial, and the gnomon interrupts the light and casts a shadow on the paper. Position your sundial on the ground and record the shadow cast on the sundial. Make three measurements: at the beginning of class in the middle of class and just before going back inside.

#### **Part B. Tracking the Flashlight**

4. The flashlight can simulate the movement of the light. Experiment with what happens to the shadow on the sundial with the sundial fixed and the flashlight moving past. What is the same or different if the flashlight stays in fixed in position and the sundial moves past it?

#### **Part C. Apply the Models to the Sundial Observations**

5. During the time between marking the shadows on your sundial, discuss how both the moving Sun/fixed Earth model and the spinning Earth models describe the motion of the sundial. What is an appropriate argument? For example, we “know” that the sun makes the shadow because we see the shadow cast onto the piece of paper. An argument is not casting accusations and inflammatory remarks at those who hold the opposing view.

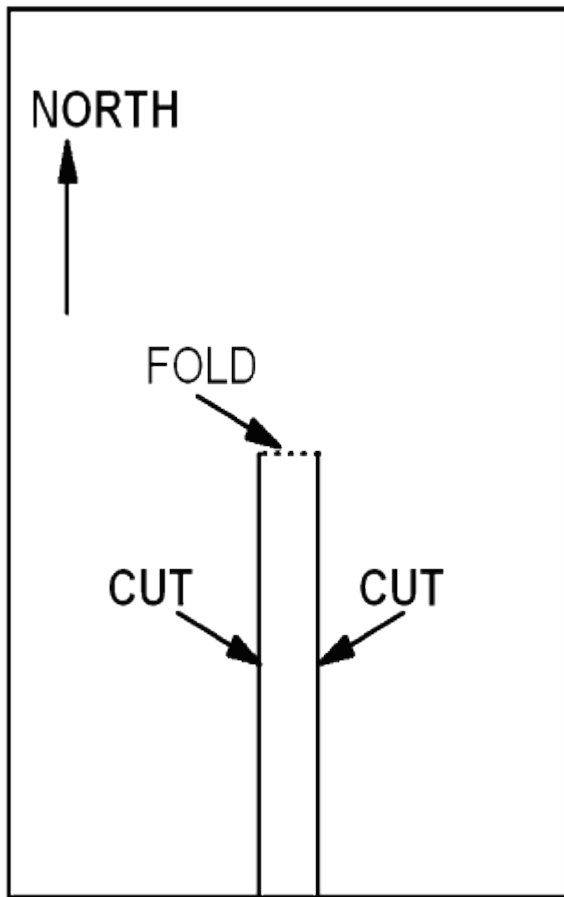
## Worksheet: A Paper Sundial

Maureen Dooley, B.S.Ed.

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SUNDIAL INSTRUCTIONS: best reproduced on heavier stock

- A. Cut along the solid lines.
- B. Fold the "tongue" up vertically at the dotted line.
- C. The sun from the south will cast a shadow towards the north. Every hour, mark the location of the shadow.



## 4. Assessment

**Learning Objective** - Evaluate the fixed Earth (moving Sun) model and the spinning Earth model to explain why the plane of oscillation of the pendulum moves and why the sun's shadow moves.

**Procedure:**

1. Join one of three groups to explain the movement of the plane of oscillation of the pendulum. First group- will present the evidence for the fixed Earth/moving Sun model. Second group- will present the spinning Earth model. Third group- will define criteria to judge the validity of the arguments. Groups do not need to be of equal size.
2. Groups 1 and 2 - Write down the evidence that you have to explain the movement of the plane of oscillation. Use examples and the data that you have collected. Come up with compelling arguments as to why this argument is correct. Prepare a 3-5 minute presentation as to why this is the better explanation. You may use charts and posters, present a play, sing or use some other creative method, but you will be judged on the evidence.
3. The third group will act as peer reviewers. What must be described to best explain the movement of the plane of oscillation? How does this explanation also explain why the shadow moves on the sundial? Anticipate several of the points each group will present and prepare a checklist of what should be mentioned.
4. The first two groups make their presentations. The third group listens to both presentations. They can then ask three questions of each group. The third group then adjourns for 3-5 minutes to decide which was the more complete and effective presentation. The third group then presents its decision and reasoning to the entire class.

**Extension:** Predict the behavior of the pendulum in the southern hemisphere.