Amgen Award for Science Teaching EXCELLENCE

2008
Winning Lesson Plan from Boulder, Colorado

Tools for Astronomical Measurements II – The Sundial and Sun Hemisphere

by Haydee G. Phelps
Summit Middle Charter School

Subject: Earth Science; Astronomy
Grade Level: 7–8
Duration: Three 60-Minute Class Periods

Overview and Purpose

Students will build their own measurement apparatus in order to engage in the scientific processes of observation, data collection and recording, and analysis. They will, through background information and repeated cycles of observation, develop and test hypotheses about the relative motion of the sun with respect to the earth. They will develop explanations of time, day and night, and the changing motion and position of the sun in the sky. They will increase understanding of how scientific research adds to our knowledge even while its theories remain subject to revision.

Innovation

This lesson requires students to construct their own apparatus for making observations, a common component of professional and academic scientific research not often incorporated into science instruction. While the students do not design the tools, as the guidelines for construction are detailed in the procedure, all students will benefit from building a basic piece of measuring equipment and using it to collect meaningful data. Additionally, one of the required extension activity choices offers a design element and may be selected by students for whom the tool-building component of the lesson was particularly engaging.

This lesson is inquiry-based and interactive, modeling the scientific process in a meaningful and realistic way. It begins from the students' daily experiences and guides them towards potential scientific questions. Though there are guiding questions for the students, the lesson does not drive students toward an exclusive and particular conclusion. The procedures are flexible, allowing for each student to perform a slightly different, individualized experiment. Students can compare their work and decisions at any stage. This models a highly interactive "community of scientists" during the activity.

One of the lesson's key strengths is that it presents questions about the relative motion of the earth and sun that cannot be answered conclusively based on the data collected. I always enjoy the classroom discussions that ensue because the students are authentically prompted to the next step of asking what different additional tests or observations could be made to verify their final conclusions and support their analysis. The design of this investigation also aims to address the fact that most middle school students already "know" that the earth orbits the sun and have a hard time understanding why anyone could could have thought otherwise. I believe it is important to guide students to an understanding of how scientific theories evolve and how knowledge gathered by scientific research is subject to revision.

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Overview and Purpose (Cont'd)

The distinction between fact and theory can be abstract and difficult at this age and this lesson serves to make these ideas more concrete by referencing a clear example.

In the second part of the lesson (see page 11) students use a different piece of apparatus, the "sun hemisphere," useful here because it provides an inverse data set. On the sun hemisphere students can literally see the path of the sun across the sky. This is indeed visual representation of the interpretations made by many of the students based on the sundial. For many students this provides an "ah-ha" moment and especially for the students who had trouble visualizing the sun's motion based on the sundial data, this second data set provides clarity. The students can also see that a single scientific question can be addressed in more than one way. They gain appreciation for diversity of approach and competition as driving mechanisms of quality research and that the reproducibility of observational evidence is not limited to scientists simply re-doing each others' experiments.

This lesson provides for different preferences in learning style and for assessing performance of various science process skills. All students are expected to meet the benchmark, but advanced students or students with particular strengths or interests may modify the activities to their preferences. Examples include the number of measurements a student decides to make and the level of detail with which they formulate and evaluate their hypotheses. In addition, the required extension activities cater to a variety of interests and abilities by providing a scientific, engineering, mathematical and literary or dramatic option of reasonably similar depth and challenge. Finally, by developing questions that require particular process skills, I am able to evaluate each students' aptitude in the areas of observing (see page 12, Concluding Questions 1–3), inferring (Questions 4, 6–7), interpretation and analysis (Questions 5–10 with number 5 being a calculation), and predicting and modeling (Questions 11–15).

Curricular Context and Unit Goals

This lesson is incorporated into an astronomy unit. It is the primary means of instruction relating to the relative motion of the earth and the sun. The goals of the unit include addressing the following standards and benchmarks. At the conclusion of the unit, students have a good understanding of the spatial and temporal relationships of our solar system including the relative motion of the earth, sun and moon and the phenomena arising as a result of these motions. In addition, as astronomy may well be regarded as "the original science," it is an excellent venue for teaching about the nature of scientific investigation, its methods, and its distinction as a particular way of developing understanding.

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Educational Standards Addressed

Standards are quoted from Colorado Model Content Standards

Science, Colorado Department of Education, Amended 2-8-07, http://www.cde.state.co.us/coloradoscience/ScienceStandards.July 2007.pdf

Colorado State Standard 1
Students apply the processes of scientific investigation and design, conduct, communicate about, and evaluate such investigations.

In this lesson students must use the scientific processes of observation, data collection and recording, and analysis. They must carry out an investigation of the sun's motion in the sky and communicate with each other and the teacher about their findings. They must evaluate the results of their investigation through class discussion and written responses to targeted questioning.

Colorado State Standard 4
Earth and Space Science: Students know and understand the processes and interactions of Earth's systems and the structure and dynamics of Earth and other objects in space.

This lesson investigates the relative motion of the sun and the earth in an attempt to help students understand the causes of night and day, the motion of the sun in the sky, and to evaluate these phenomena in terms of an acceptable model of the solar system.

Colorado State Standard 5
Students understand that the nature of science involves a particular way of building knowledge and making meaning of the natural world.

This lesson asks students to evaluate the validity of the heliocentric versus the geocentric model of the solar system based on particular observations. It requires students to develop an understanding of the distinction between "support" and "proof" in science. Students come to understand why the geocentric model of the solar system was acceptable for a time and are asked to recognize that scientific theories are subject to revision as new observations emerge. Finally, they must relate the results of the investigation to prior knowledge.

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Benchmarks

Benchmarks (what the students can do): At the conclusion of the lesson students will have succeeded in constructing an appropriate measuring device and will have used it correctly to collect at least three reasonable measurements.

- They will have formulated original hypotheses based both on prior knowledge and their observations.
- They will have evaluated their hypotheses in light of the data collected and revised them as needed.
- They will have made a final assessment of the data including formulating conclusions about the causes of night and day, the passage of time, and the position and motion of the sun in the sky.
- They will evaluate these conclusions in light of accepted models of the solar system.
- They will recognize that hypotheses are highly mutable and meant to be revised as new data is collected and that a scientific theory is also not permanent, but subject to revision as new investigations reveal additional perspective.
- The students will be able to articulate supporting evidence for the geocentric and heliocentric models of the solar system and will be able to explain why more than the relative motion of the sun and earth is needed to favor one model over the other.

Materials

The required materials are (per student):

- a plastic straw,
- a paperclip,
- a piece of cardstock,
- tape,
- ruler, and
- a pencil.

At least one compass is required to locate North and a sun hemisphere is needed for every 3-4 students. The sun hemispheres can be purchased from many scientific supply companies and constructed by the teacher or the students.

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Procedures

See pages 6-12 for instructional materials.

Activities Outside of Classroom

See page 10, Part 1: Extension Assignment in the following instructional materials.

Instructional Materials

Perhaps the best way to communicate the lesson is through the original instructional materials. They have been included here, annotated and reformatted instead of as a paper attachment. In the student handouts there is more space for notes and scratch work, the pictures and tables are larger; the directions are more widely spaced and the page breaks occur in more logical places.

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Purpose

(We begin with a discussion aimed at calling upon prior observation and knowledge.)

It is fascinating to think scientifically about things that happen every day—literally! The sun rises, travels across the sky, and then sets. 24 hours comprise each and every "day," but there are more daylight hours in the summer. Your shadow is longer in the morning than it is in the late afternoon. Solar panels are almost always angled to the south. Can you think of some more things like these?

All of these things happen the way they do because of the ***spatial***, meaning___________________, and ***temporal***, meaning___________________________, relationships between the earth and the sun. This can be summarized as the ***relative motion*** of the earth and sun.

We will develop hypotheses and make specific predictions about occurrences due to the relative motion of the earth and the sun. Then, we will build and use measurement tools to test those ideas.

Introduction

(The students are prompted to commit to their prior understandings by recording some written thoughts to the questions posed in the discussion.)

First, think about some important questions. What causes time of day? Why does the sun travel across the sky? Why does southern exposure guarantee more sun? Why does the length of the day always stay the same? Why are there more hours of daylight in the summer? Are these things the same everywhere in the world?

Write down some of the thoughts that you have about these phenomena:

"I think…"
(The students are provided with about half a page of space to record their thoughts.)

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Part 1: Collecting Observations of the Sun Using a Sundial

(The students proceed to build their sundials and set them up outside for the first measurement.)

Building the Tools

To begin exploring some of these questions, we will build a very simple sundial. In its simplest form, a sundial is a straight rod of known height placed in the sun to cast a shadow. ***Shadow sticks*** or ***obelisks*** are very simple sundials. The shadow-casting piece of a sundial is called a ***gnomon***.

Procedure for Making a Sundial

You will use a cardstock base, a paper clip, masking tape and a drinking straw to build your sundial. You will also need a pencil to mark the cardinal direction NORTH.

1. Using a ruler, draw a straight line down the center of the longer dimension of the cardstock base. Label one end of the line NORTH.
2. Rend a paperclip into a 90° angle.
3. Using masking tape, attach the wider part of the paperclip to the cardstock so that it is "lined up" on the line opposite from the side that says NORTH. The thinner side of the paperclip should be sticking up at a 90° angle to the base and lined up with the NORTH line.
4. Measure the length of your straw in centimeters. Record it on the base.
5. Slip the straw onto the thinner end of the paperclip so that it stands up at a 90° angle to the base and is aligned with the NORTH line.

Procedure for Making Measurements with the Sundial

- Align your sundial with true North. There will be a line on the ground outside that is aligned with true North. (To do this yourself at home, you can use a compass to find the direction to magnetic North. That direction is then corrected for the angular difference between the direction to the magnetic North pole and the geographic North-pole. This so-called magnetic declination is different depending on where you are on the earth.)
- Place your sundial on the ground so that the line down the center of the base of your sundial is lined up with the true north line on the ground. It is a good idea to weight it down so that it does not move.
- To make a measurement you must trace the shadow to the edge of the base, record the time and record the length of the shadow in centimeters. You can write the time of the measurement and the length of the shadow right onto the traced line of the shadow on the sundial. You should also put these two measurements into a data table (see page 9).
- Leave your sundial lined up in the same position so that you can return to make additional measurements.

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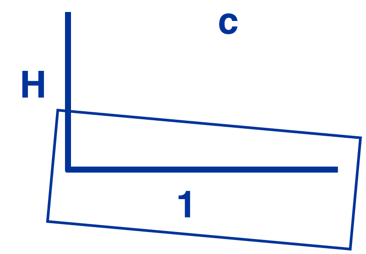
Sundial Theory

In the space below you should record your notes on how sundials work.

(This is done by means of a frontal discussion in class conducted between measurements. Typically I will project the diagram below and we will discuss what each part represents. Then, I draw the sun to the upper left of the diagram and draw lines representing the sun's rays. A line falls from the tip of **H** *to the end of* **1** *and we discuss what that line represents. We briefly discuss the kind of math needed to determine the various angles and lengths in the diagram and the students explain back to me what types of things about the sun we could determine.)*



Predictions (Hypotheses) and Observations

(The students proceed to make their next set of hypotheses and then another round of measurements. At this point some students begin to modify their plan, making measurements at different intervals and coming up with original questions.)

You will make a series of predictions (hypotheses) based on what you know about the daily motions of the sun in the sky and sundial theory. You will perform several rounds of observations, making data-driven determinations for each of your hypotheses and developing new hypotheses as you go. You are required to make at least three sets of observations approximately 10 minutes apart, but may choose your own time interval and number of measurements to make.

Below are some questions to address with predictions (hypotheses). You should also come up with some of your own.

1st Set of Predictions (based on your background knowledge and prior observations of the world):

1. How will the dimensions of the sundial change over time?
2. How will the dimensions of the shadow change over time?
3. How will the lengths and angles in the diagram above change over time?
4. How will the position of the sun change over time?

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2nd Set of Predictions (based on your first round of sundial data):

1. Did your data support your previous predictions?
2. Do any of your earlier predictions need to be revised?
3. When during class will the shadow be longest? Shortest? Will there be maximum or minimum lengths?
4. When during class will the angle opposite side **H** be greatest? Least? Will there be a maximum or minimum angle?
5. Why? What kind of motions of the sun and/or earth may be causing this? Describe a test you could do to verify it.

3rd Set of Predictions (based on your first and second set of sundial data):

1. Did your data support your previous predictions?
2. Do any of your earlier predictions need to be revised?
3. Can you extend your predictions to cover longer periods of time—like a whole day or a whole month or year?
4. Is this simple sundial adequate? If not, what are some of the problems with its design? Will it work anywhere in the world? What factors could be accounted for to make a more useful sundial?

Data Tables *(In the students materials, these tables occupy a full page to allow for plenty of space to record their predictions and observations.)*

Set of Predictions	Predictions
1st Set: Before any sundial measurements are made	
2" Set: After 1st Set of sundial measurements are made	
3" Set: After 2nd Set of sundial measurements are made	

Round	Any Support FOR or AGAINST Your Predictions?	Time	Length of Shadow (cm)
1st Measurement			
2nd Measurement			
3rd Measurement			

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Part 1: Extension Assignement

(To be completed outside of class as a homework project.)

You must choose one of the following activities to complete this lesson. The options are discussed in class and are due in one week.

A. You can build and demonstrate the benefits of an improved sundial. Try doing a bit of background research to help you design it. There are several solutions to the geometric problems associated with sundials.

B. You can carry out an original experiment of your own design using your sundial. You must state the question you intend to answer, make a prediction, record your procedure, take quantitative measurements (data), and analyze the data to produce a discussion of your results and a conclusion with regard to the original question and prediction. Account for sources of error.

C. You can use your measurements and basic trigonometry to solve for the altitude of the sun in the sky based on several measurements made using your sundial. Draw a diagram and label the side lengths and angles. Solve for the angle opposite side **H**. Include an explanation of each geometry concept used in your solution. Show all of your work.

D. Research the history of sundials in ancient through modern astronomy and prepare an informational brochure poster, or short (5-7 minutes) dramatic performance to share with the class. For all final products you must include a typed works cited in MLA format.

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Part 2: Plotting the Path of the Sun

(Students work in groups to plot the position of the sun. They work on the questions in between measurements.)

The dome represents the sky and the mark represents where the sun appears in the sky at that particular date and time. As the earth rotates, the sun's position in the sky changes throughout the day.

Procedure for Making Measurements with the Sun Hemisphere

1. Get a clear hemisphere and a wet erase pen.
2. Go outside and find the chalk **N-S** line drawn on the ground. Lay your hemisphere on the ground so that it is aligned with the **N-S** line. Draw an outline with chalk on the ground around the base in case the hemisphere gets moved by accident! It must stay in the same position.
3. Carefully move the tip of the marker close to the plastic hemisphere, but do not let the marker touch the sphere
4. Move the marker around the outside of the dome until the shadow cast by its tip falls directly on the cross point of the **X** mark on the base diagram. Mark a dot on the hemisphere at this location.
5. Label the time of your observation in small print just to the side of the point.
6. Do this every 15 minutes. In the meantime, begin to answer the Concluding Questions (see page 12) on separate paper.

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Concluding Questions

(Answer the following questions on separate sheets paper and attach.)

1. Determine from the data which compass direction the sun rose from this morning. Explain how you know.
2. Determine from the data in which direction the sun travels across the sky. Explain how you know.
3. Determine from the data in which cardinal direction the sun will be located at noon. Explain how you know.
4. Make an inference based on your data from the class hour about how the altitude of the sun in the sky changes during the course of the entire day.
5. Using data that you collected, calculate the rate of relative motion between the earth and the sun.
6. By reference to data that you collected and inference, explain the cause(s) of time of day.
7. By reference to data that you collected and inference, explain the cause(s) of sunrise and sunset.
8. Does your data set support the notion that the earth orbits the sun? Explain your reasoning.
9. Does your data set support the notion that the earth rotates? Explain your reasoning.
10. Does your data set support the notion that the sun orbits the earth? Explain your reasoning.
11. If we accept the theory that the earth rotates on its axis as it orbits the sun, how do you think your observations would change if the earth rotated slower? What if the earth did not rotate at all in its orbit?
12. Answer number 9 assuming the geocentric model of the solar system.
13. If we accept the theory that the earth rotates on its axis as it orbits the sun, how do you think your observations would be different if you were observing in the southern hemisphere?
14. Explain why the geocentric model of the solar system seemed to be a reasonable hypothesis (theory?) based on early astronomers' observations of the motion of the sun in the sky.
15. Evaluate the potential for this experiment to provide evidence for a particular model of the solar system. Is there a set of observations of the motion of the sun as viewed from the earth that could disprove the geocentric model of the solar system?