# Sun and Shadows Unit: Plans for 2005-06 School Year

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This unit is based on work with students in the 2004-05 school year and includes the following experiences:

(1) Students go outside and observe and record the shadow of a shadow stick on a shadow board.

(2) Students create scale drawings.

(3) Students create side-view scale drawings of something casting a shadow.

(4) Students make inferences from side-view scale drawings which show the sun angle at noon on each of the equinoxes and solstices.

Rationale for having students go outside and observe and record the shadow of a shadow stick on a shadow board: After students have done it themselves, they will be able to interpret records made on other occasions more easily, and they will be able to work with records from the fall and spring equinoxes and the winter and summer solstices. Each time students go outside, observe, and make records, they make discoveries and gain understanding – not in a set order – about the sun path in the course of a day, the changes in the sun path over the course of the year, and about the skills of record keeping. Students work in heterogeneous groups because they will naturally discuss and argue various points and become aware of aspects that they had overlooked. Discoveries may lead to understanding, or understanding may lead to observations – and none of this occurs in a set order. Just as when we re-read a well-crafted novel we are ready to notice additional aspects that escaped our notice the first time because they were too complex, students often notice new aspects of these complex phenomena at the time that they are ready to learn from those aspects. Teachers have an important role in guiding these discoveries.

Rationale for having students create scale drawings (which could be done before or after the first time students use the shadow boards outdoors): It is important to address scale and proportionality in science class. When students apply proportional reasoning to facts about the solar system, many misconceptions can be uncovered (as opposed to being, in effect, paved over and continuing to grow under the pavement, causing cracks in the foundation of understanding). For instance:

Q. How can it be that the fact that the Earth is closest to the sun in January is insignificant to seasonal temperature variation?

A. Because the seasonal difference in distance is less than 2 percent, while the 47 degree difference between the sun angle at the winter solstice and the sun angle at the summer solstice creates a much more significant effect.

Q. How can the moon be only about one four-hundredth (1/400th) of the sun's diameter and still block light from the sun in a solar eclipse? (The moon is about one fourth of the Earth's diameter, and the sun is about 100 times the Earth's diameter.)

A. Well, since the sun is about 400 times farther away from Earth than the moon is, the moon almost perfectly blocks the sun to earthlings when the sun, moon, and Earth line up perfectly.

Q. How come there aren't solar eclipses every new moon and lunar eclipses every full moon?

A. Because, given the distances, it's awfully seldom that they do line up perfectly.

Rationale for having students create side-view scale drawings of something casting a shadow: When students have the ability to make accurate scale drawings they will be able to accurately determine the sun angle from their own records. More importantly, their ability to <u>create</u> diagrams from this perspective will enhance their ability to <u>interpret</u> diagrams from this perspective, and it sets the foundation for students to grasp the importance of choosing particular perspectives for communicating important information in a diagram.

Rationale for having students work with side-view scale drawings which show the sun angle at noon on each of the equinoxes and solstices: They will discover or be reintroduced to the 47 degree difference between the sun angle at noon at the winter solstice and the sun angle at noon on the summer solstice, and relate those differences to other differences between the seasons – such as length of the day, intensity of solar radiation, and actual location of sunrise and sunset. (The idea that the sun rises in the east and sets in the west is an oversimplification which tends to create misconceptions. Understanding the variation of the sunrise locations and the variation in the sunset locations is probably a prerequisite to understanding how both calendars and navigation developed.) If students understand the differences between the seasons, the words "equinox" and "solstice" will be understood, not simply memorized.

Very detailed lesson plans for students creating scale drawings of themselves are included – as an early experience in $6^{th}$ grade science class. However, lessons should not generally be precisely planned in advance because the teacher needs to be responsive to the variety of the students' prior knowledge and experiences as well as – for the outdoors classes – the time of day and year and to any special issues about taking classes outdoors. (For instance, certain experiences promote a sense of ownership of the shadow boards which might be important in some circumstances, while in others the teacher might want to minimize the procedural knowledge aspects.) That said, this document includes the "Sun and Shadows Outdoors" lesson plan which was used with classes during extended periods after Scale Drawings had been completed and after one experience of using the shadow board – which was already set up, thus no sense of ownership developed – outdoors on the autumnal equinox.

## Personal Measurements / Scale Drawings – Lesson Plan Day 1

Purposes: Introduce scale drawings and proportionality. Introduce SI Units. Students practice making and recording measurements with meter sticks and metric rulers. Students collaborate as needed. Each student creates a scale side-view drawing of him/herself on graph paper and a cutout for future use with Sun and Shadows.

Materials for Day 1:
- assortment of diagrams and scale drawings on display
- assortment of rulers (4 per table)
- meter sticks (2 per table)
- a few yardsticks
- "Personal Measurements … " handouts for students

Point out or pass around the diagrams and scale drawings. Mention that such things are very useful to scientists, engineers, designers, architects … etc.

*You're going to make scale drawings of yourselves.* Discuss these questions: *If I want to make a scale drawing of myself, what do I need to do? What does that mean, "scale drawing"?* Write new vocabulary on overhead or blackboard.

The discussion for "scale drawing" might include:
- "Proportional" means that if one part is [twice / one-half / one-quarter / one-tenth] life size, so is everything else. "Proportion" is another word for "fraction" or "ratio."
- "Scaled down" (or "scaled up") means that it is smaller (or bigger) than life size, and all parts need to be proportional
- A "scale drawing" may be smaller or bigger than life size

The discussion for "what I need to do" should include:
- Decide or find out how detailed the drawing is to be and thus what measurements are necessary
- Decide or find out what the scale needs to be
- Make and record measurements
- Use paper with grid lines (for convenience) and mark some of them
- Indicate the scale used

*Let's try out a measurement, and see what decisions need to be made. Say I want to measure from my fingertips to the floor.* [Hold a yardstick upside-down (with 36 inches at the floor and 0 at the top) and call a student up.] *Could you read the number where my fingertips reach the yardstick?* Write that number on the overhead.

*Let's try this again. Scientists like to check their work.* [Hold a meter stick upside-down (with 100 cm at the floor) and call another student up.] *Could you read the number where my fingertips reach the measuring stick?* Write that number on the overhead.

*I guess we'd better check those again – were they different because I used different measuring sticks, or because I asked different people to read them?* [Hold the yardstick with 0 on the floor and the meter stick with 0 on the floor, and call another student up.] *Could you read both those numbers, where my fingertips reach?* Write those numbers on the overhead.

*What might be going on?*

The discussion here should include:

- Zero needs to be at one end.
- You need to be aware of (or maybe choose) the units.

*Now, we **could** use "US Customary Units." That's feet and inches.* (Discuss.) *But this is science class, so we'll use the system used by scientists around the world, since it's important for scientists to be able to communicate with each other: This is called "SI Units"(Systeme International d'Unites) or the "metric system."*

*Pick up a long ruler from your table – what does it have on it? How many inches? … Feet? … What are the SI units on the ruler? How many centimeters? Meters? Millimeters? I wanted you to notice all those, but we're going to use centimeters for this work.*

*What measurements should you make? I've listed those on the handout.* [Put it on the overhead and/or hand it out.] *You will work with the people at your table getting these measurements, accurate to the nearest half-centimeter. There are challenges in getting some of the measurements.* [Show how to get an accurate height measurement, using a book as a "square." Show some ways to get front-to-back of head at forehead, using three rulers.] *First it is really important to fill out the top completely.*

Help students get as many of the measurements as they have time for – probably 1 or 2 measurements the first day. Collect the papers before they leave.

Name: ______________________________ Date: __________________________

Science class: ________________________ Homeroom: ____________________

Table number: _____ First names of others at your table: __________________

______________________________________________

## Personal Measurements for a Side View Drawing **All measurements need to be made in SI Units. Make sure everyone at the table has gotten the measurements at the station that matches your table number, then go on to the next station number. (After everyone at the table has done Station 6, go to Sta. 1.)**

**Required**

**Sta. 1.** Heel to toe (in regular shoes): ________________
Describe your shoes briefly (sneakers, sandals, etc.): _________________

**Sta. 2.** Floor to top of head: ________________

**Sta. 3.** Floor to chin – be careful, look straight forward, **not** up or down! ________

**Sta. 4.** Horizontal measurement of head at forehead: ________________
(Use two rulers, a flat surface behind you, and a partner to sight.)

**Sta. 5.** Floor to shoulder: ________________ Floor to elbow: _________________

**Sta. 6.** Floor to wrist: ________________ Floor to fingertips: ________________

**Additional (optional) measurements**
(Make these as needed, once you begin to sketch.)

Floor to waist or bottom of shirt: ________________

Horizontal measurement at waist, or bottom of shirt: ________________

Horizontal measurement – wall to tip of nose – head straight! ______________

Horizontal measurement – wall to front of neck: ________________

(Other – describe measurement and specify result)

_____________________________________ ________________

_____________________________________ ________________

## For Later Use – Sun and Shadows

Height in these shoes if different: ________________

Shadow length: ________________ (from heel or from toe?)

Date: ________________

Time: ________________

Other: ___________________________________________________________

# Personal Measurements / Scale Drawings – Lesson Plan Day 2

Additional Materials for Day 2:

- Graph paper (1 sheet for each student)
- Overhead acetate graph paper
- Sample set of measurements and completed sketch on graph paper

Students will need more time to get the rest of the measurements before they can begin sketching, but start by setting up the graph paper with them and then modeling for the students how to go from measurements to their scale drawing. That allows students to finish the measurements and begin drawing at their own pace.

*Today I'm going to show you how to make your scale drawing from your measurements. I know you haven't finished making measurements. That's fine. When I'm done, you should make the measurements you need as you need them for your drawing.*

*We're doing this in science class, and I want scale drawings of all the students to be at the* ***same*** *scale, and I want each student's drawing to fit on a piece of paper around this size. I have this graph paper available, and it has ¼ inch grid markings. I figured this out ahead of time: It will work for my purposes to make 10 cm = grid marking.*

Optional conversation – we did not have: *Sometime you might be making your own choice about what scale to use. What would you need to take into account?*

The list might include:

- The purpose of the scale drawing.
- The actual size of what is being drawn.
- The units on the measuring device (could be your hand).
- If there are grid markings already on the paper, the spacing of them.
- The size paper you will put it on.

*Another way of describing the scale to be used is: 10 cm = ¼ inch. Or, if I put that in a single type of unit, it turns out that the drawings will be about 1/16th life size.*

*I want to tell you that I am uncomfortable when I draw. I don't feel like I am a good artist. When I doodle, I make geometric/abstract shapes, not living things. But when I use the measurements, it turns out to look realistic. I think mine came out pretty well. I'm going to show you how I did it, and then you will do your own. For this first part, though, follow along with me; set up your paper* ***exactly*** *this way.*

Hand out **hole-punched** graph paper to each student. *Hold the paper "landscape" style, with the holes across the top.* Put the grid paper on the overhead. *Put your name across the upper left between the first and second holes*. Draw holes and write "Your Name" on the overhead. *Now, what is the scale we're going to use? Each grid line is worth 10 centimeters. So, how can we show that? Here's a traditional way:*

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|   |   |          |              |
0  10  20         50            100 cm
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(Draw the preceding and have them duplicate it, with the tic marks **on** grid lines, in the upper right quadrant of the paper, and then alternately shade the upper part and the lower part between the tic marks.)

*Now, I want the drawing to end up close to the left-hand side. Also, most of your references started at the floor, or at the wall. So put your heel at an intersection of grid lines about two grid-lines above the "scale" and six lines in from the left side.*

*You'll find it useful to have some grid lines labeled (but out of the way) up the side until you get to a height at least as tall as you are. I can't label each grid line because my numbers don't fit: I'm labeling every other one. Put a tic mark to show which grid line you're labeling, and label them like I am. 0, 20, what's this? 40, … I am 165 cm tall, so 180 is enough.* Point out that their "180" will not come as close to the top of their graph paper as it did on the overhead (because the overhead version was enlarged).

*Check how long your foot is. Mine is 24cm, here's 20, here's 25, so just a tad shorter. This part you can't copy – you need to do it according to your measurements. Most people stand with their head pretty much centered over their feet. Put a tic mark at the top of your head. Here's 165. Label it with a squiggly arrow so it's easy to tell what the measurement was. The squiggly arrow gets it out of the way of the drawing, and makes it clear what the number goes with. That's a standard engineering way to label things in drawings which also have straight lines. Now, where should the back of your head be, and how could you check that?* Ask for a volunteer, open the cabinet door, have them stand on the far side. Have them move forward and/or back until their heels are both lined up (visually, for you) with the cabinet door. Have them face front, $90^{o}$ from where you are. Sight along at the back of their head – discuss whether there is space, or the head lines up, or hides partially behind the cabinet door. Set up the head on the overhead like yours is. Show how square most chins are. Be brave, draw in front of them. Leave it partially done, show them a finished one … use your judgment.

Return their Personal Measurements papers to them, and let them finish measurements and do their drawings – a re-iterative process.

Clean up (and assign homework?) five minutes before the end of the period. If some students are done before that, encourage them to embellish their scale drawing or have them help others more – and collect their work. If the pace of your class is slow or if more than a few minutes of the period was taken up with other things, then you may decide to devote part of another class to finish up. In that case, collect all the work. Otherwise, you may decide to assign the completion of the scale drawings on graph paper as homework for those who aren't done. Those students will need to take their Personal Measurements sheet and graph paper home. Stress that they need to return to class with both sheets remaining neat and unwrinkled, even if either is still incomplete.

## Personal Measurements / Scale Drawings – Lesson Plan Day 3

Plan an activity which students can do independently when they complete their work. About 3/4ths of the students will be done in about 20 minutes. (Collect any Personal Measurements sheets and look at any scale drawings that students finished since last time.)

Additional Materials for Day 3:

- Sample scale cutout(s)
- 1/8th of a sheet of tracing paper for each student
- 1/6th of a sheet of meaningfully* colored copier paper for each student (*I used yellow paper for all the students in yellow class, for instance.)
- Glue sticks (1+ for each table)
- Scissors (2+ for each table)
- Several magnetic/adhesive pads (for the teacher)

Model these steps for students, and write them on the board: (1) Place the tracing paper on top of the scale drawing on graph paper. (2) Trace the drawing onto the tracing paper. (3) Spread glue evenly on one small sheet of the right colored paper, over the entire region where the figure will be placed, and lay the tracing paper on that. (4) Cut out the figure neatly, with particular care to cut close at the top half of the head and at the feet. (5) Write your name on the back (or on the front, if that's what you want).

Return the scale drawings to students, put out the supplies, and circulate while students work on this. Emphasize that the order of the steps does matter. If anyone needs extra time, make arrangements for them to come in to the classroom to finish.

Collect the graph paper scale drawings, and the traced and glued figures. Each figure will need a small magnetic/adhesive strip cut to size and attached. A small piece is sufficient.

## Sun and Shadows Outdoors – Lesson Plan

This lesson does not fit in one 45 minute period.

Purposes: Familiarize students with directional compass, carpenter's level, meter stick. Increase student awareness of length and direction of shadow in relation to position of sun. Increase student awareness of change in shadow position and length over long and short periods of time. Students collect personal shadow-length data.

Materials for each group

- 4 - 6 meter sticks
- Shadow board
- Shadow stick
- Large sheets of paper taped to shadow board
- Shims for 3 corners of the board – old science books work well
- "Shadow Board Information" sheet on a clipboard with a pencil
- "Personal Measurement" sheets on one or two clipboards with pencils

Materials which can be shared, but one for each group would be better

- Directional compass
- Carpenter's level
- Pencil.

Show the boards which will be used, and ask – *If we want to draw the shadow of this shadow stick with each class to see how the shadow changes throughout the day, what do we need to make the same so it is a fair comparison? What if we can't leave the board outside?*

The discussion here should include:

- The North arrow needs to be set up the same way.
- The board needs to be level.
- It doesn't matter whether the board is in the same spot or not.

Decide whether to teach the class how to use a compass and whether to take true north vs. magnetic north into account – while indoors you can place the compass right on the overhead and project the image right onto a shadow board. [I did go over compasses briefly, but not true vs. magnetic north.]

Decide whether to teach an efficient and accurate way to measure shadows or not – i.e. lining up a meter stick or two on the ground, having a different person checking the length, etc. We've discovered that the most useful measurement is **toe**-to-tip-of-head, not **heel**-to-tip-of-head.

Set up the students in heterogeneous groups of 6 – 8 students. Pass the "Shadow Board Information" clipboard around the group. Each student should fill in his/her name. Prepare one or two clipboards with the Personal Measurements sheets for the group. Have students take on jobs – first, two to carry their group's board. (Have the students look at each other and agree within the group on who will carry the board.)

The other jobs are to carry other items outside and to be responsible for proper use outside: meter sticks, clipboards, and shims for the group; shadow sticks, compasses, and levels for the class; and if the teacher carries the markers it forces contact with the groups before drawing takes place, which is useful.

Once outside, position groups about 15 feet apart and help them first to get "N" pointing north, and then to both level the board and screw in the shadow stick. They should then draw the shadow with the right color marker and write on the "Shadow Board Information" sheet what time it was done. Then they should measure the shadows of everyone in the group, with people standing as straight as possible. They should leave the shadow stick in the board while they are measuring their shadows.

Have students notice how much the shadow moves in those few minutes if they haven't on their own. Have students collect the supplies and return inside.

After all classes have met, and before removing the sheets from the shadow boards, write the date and time each shadow was drawn, and mark key aspects of the shadow board on the sheet so that the event can be reconstructed.

## Further Sun and Shadows Ideas

There are examples of completed student work for most of these ideas.

Add shadow and sun altitude angle to scale drawing of self. (Purpose: Increase student awareness of proportionality in multiple dimensions.) Materials might include the shadow boards and flashlights (for students to reconstruct where the sun might have been) and oversized protractors (to help students visualize the angles involved).

Starting with a side view sketch of some blocking object or person and shadow with sun angle, add either another <u>height</u> or another <u>shadow length</u>, and show how to find the fourth piece of information using the same sun angle.

Discuss reasons the sun angle would be the same or different – how do time of day, day of year, and location (latitude and/or longitude) affect the sun angle? (Go over a good answer to the Ecuador/Lexington flagpoles-and-their-shadows question, and brainstorm all the <u>reasons</u> that they were different.)

Look at shadow stick shadow tracings from one date and discuss and predict what is expected on another date. (Definitely do this before going out for the winter solstice.)

Discuss sources of error in sun angle measurements in the personal scale drawings.

Shadow lines – measure and note direction of full class shadow line at different times of day. (To create a shadow line, have one student start the line and each additional student stand just inside the previous student's shadow head.) Count students needed to create a shadow line to match the flagpole's shadow, predict how many will be needed to create a shadow line at another time of day. Use the scale people to re-create the situation on the blackboard with the sun angle drawn in.

Read aloud the whole book The Librarian Who Measured the Earth, or my version of it, and use props to show the angles involved. The props I've developed include: globe and string to show why the sun's light can be considered to be parallel, cardboard cut to fit globe with parallel "sunlight rays" drawn on to closely match a cross-sectional view of Earth which can be manipulated on the overhead projector – because then the effect of the changing tilt on the shadow can be shown clearly.

Given a side view sketch of a picnic table with a canopy, ask students to show where the shade from the canopy would fall at noon on an equinox and the summer solstice. In this assignment, students need to figure out that they need to construct angles on the side view sketch, they need to figure out where to construct them, and then to construct them. This classroom assignment allows the teacher to determine the depth of each student's understanding of side views and angles, and smoothly move into assisting the student as necessary.