IT'S ILLUMINATING!

The relation between sunlight and temperature variation on earth

Teacher's Playbook

http://www.purplemoon.com/Stickers/sun-earth.jpg
It’s Illuminating!

Developed by:
David Schuster, Betty Jeffrey, Adriana Undreiu, Bill Cobern, Renee’ Schwartz

The Mallinson Institute for Science Education
Western Michigan University

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WHAT THE UNIT IS ABOUT

Two aspects: basic science and application

This unit includes both basic science and its applications to the real world. The science is about light energy and how it varies with angle and distance, while the applications are the effects of sunlight on temperatures on earth, explaining why temperatures vary with location (latitude) and with time of year (seasons).

The basic and applied components of the unit are as follows:

1. Basic science
   - Light carries energy, and can heat a surface.
   - The energy received depends on the angle of light to a surface, on distance from the source, and on duration.

2. Applications
   - Temperatures on earth vary with location (latitude). (Due to different angles of incoming sunlight at different latitudes).
   - Temperatures vary with time of year. (Due to the tilt of the earth’s axis, which gives rise to different angles and durations of sunlight in summer and winter).

In this unit, these two applications are approached as observed mysteries to be explained, drawing on both the basic science and on the geometry of the earth-sun system.

Ground-based and space-based viewpoints

We approach each application from two points of view. First from the ground-based viewpoint, observing the path of the sun across the sky, and how its angle varies with location and with time of year. Second, we view the earth-sun system as if ‘from space’, involving the geometry of a spherical earth spinning on a tilted axis while orbiting the sun.

Note. From the first point of view we note the observed behavior of the sun at different locations and times of the year, but do not know why it behaves this way. Here the second point of view provides an explanation, in terms of the geometry of the sun-earth system.
BROAD STANDARDS AND UNIT-SPECIFIC INSTRUCTIONAL OBJECTIVES

We present both broad standards statements for the domain and detailed instructional objectives for the unit.

A. BROAD DOMAIN OBJECTIVES AND NATIONAL STANDARDS

Standards documents use a broad brush for stating the main objectives for a domain. Broadly stated, our domain objectives for this unit are as follows.

Students will be able to state that light carries energy, and say qualitatively how the energy received on a surface depends on angle, distance from the source, and duration. Using these principles and geometry, be able to explain why temperatures on earth depend on location (latitude) and on time of year (seasons), from both a ground-based perspective and a view from space.

Detailed unit-specific instructional objectives consistent with these broad domain standards are given below.
B. DETAILED UNIT-SPECIFIC INSTRUCTIONAL OBJECTIVES

Detailed objectives specific to this unit are given below. They are written to guide teaching, learning and assessment. Page or section numbers given are from standards documents.

<table>
<thead>
<tr>
<th>BASIC SCIENCE:</th>
<th>Page references to relevant standards documents *</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Light, energy, and variation with angle, distance and duration</strong></td>
<td></td>
</tr>
<tr>
<td>1. Be able to state that light carries energy, and say how one could demonstrate this.</td>
<td>MICH 133, U 13</td>
</tr>
<tr>
<td>2. Be able to describe how light energy received on a surface depends qualitatively on <em>angle, distance and duration</em>, and how one could demonstrate each dependency</td>
<td>AAAS 66, MICH 133, NAEP 37 E.11, Table 19 p45</td>
</tr>
<tr>
<td>3. Be able to explain the angle effect above in terms of area illuminated by a light beam at different angles to the surface, illustrating this diagrammatically.</td>
<td>AAAS 66, MICH 133</td>
</tr>
<tr>
<td>4. Be able to explain that virtually all energy on the earth’s surface comes from the sun and that sunlight warms the earth’s surface.</td>
<td>NAEP E8.11, Gd 4 &amp; 8, MICH U 13 NSES 159, 161, 189, AAAS 83, 85,</td>
</tr>
<tr>
<td>5. Be able to describe earth’s temperature variations with location and with time of year.</td>
<td>MICH 126, 133</td>
</tr>
</tbody>
</table>

APPLICATONS:

A. Temperature variation with latitude

| 6. Be able to describe and compare the apparent (observed) motion of the sun in the sky from different locations on earth. | AAAS 68, 336, MICH 29, U 18, NAEP 33, NSES 134, 159, |
| 7. Be able to explain why average temperatures vary with latitude on earth, from both ground-based and space-based viewpoints. (in terms of different angles of sunlight to the ground). | MICH 126, U 19 |

B. Temperature variation with time of year (the seasons)

| 8. Be able to compare the apparent (observed) motion of the sun in the sky at different times of year (midsummer and midwinter). | MICH U 18, 20, 29, NAEP 33, + NSES K-4 134, 159. |
| 9. Be able to explain why temperatures on earth vary with time of year (seasons) from both a ground-based perspective a space-based perspective. | AAAS 66, 68, 69, MICH 29, 39, 131, 134, NSES 161 |
| 10. Be able to explain why distance from the sun is *not* a factor in causing earth’s seasons. | MS8 17, AAAS 217, 270 |
| 11. Be able to use the science and geometry to predict what the effects would be on earth if certain factors were different (e.g. if the earth’s axis were not tilted, or earth’s orbital distance varied significantly in a very elliptical orbit). | MICH 15, AAAS 217, 270 MS8 17 |

**Related mathematical objectives**

<p>| 12. Be able to determine area by counting small squares within a given outline. | AAAS 223 |
| 13. Be able to represent the earth-sun system and relevant motions by geometrical diagrams and sketches. | AAAS 268 |
| 14. Be able to relate a change in one quantity to a change in another. | AAAS 217 |</p>
<table>
<thead>
<tr>
<th><strong>SCIENTIFIC INQUIRY AND NATURE OF SCIENCE OBJECTIVES</strong></th>
<th><em>References to standards documents</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Be able to generate scientific questions based on observations.</td>
<td>MICH EL1 15</td>
</tr>
<tr>
<td>2. Be able to state that scientific questions are answered by gathering and analyzing evidence.</td>
<td>MICH U 2</td>
</tr>
<tr>
<td>3. Be able to design and construct simple investigations</td>
<td>MS 8 p15.</td>
</tr>
<tr>
<td>4. Be able to distinguish between observations and inferences.</td>
<td>MICH U 2</td>
</tr>
<tr>
<td>5. Be able to decide between alternative hypotheses or solutions, based on scientific theory and/or observations.</td>
<td>MICH U 4</td>
</tr>
<tr>
<td>7. Be able to develop solutions to problems through reasoning, observation and/or experiment.</td>
<td>MICH EL2 15</td>
</tr>
<tr>
<td>8. Be able to show how basic principles of science and math apply in real world situations.</td>
<td>MS 8 17</td>
</tr>
<tr>
<td>9. Be able to use models to explain and predict phenomena.</td>
<td>AAAS 270</td>
</tr>
<tr>
<td>10. Be able to state that a model’s usefulness can be tested by comparing its predictions to actual observations.</td>
<td>AAAS 270</td>
</tr>
<tr>
<td>11. Be able to explain that models are not the real thing but are devised to represent features of a real thing or process, to enable us to understand and make predictions about the real thing.</td>
<td>AAAS 267 -</td>
</tr>
</tbody>
</table>

*AAAS = AAAS Benchmarks for Science Literacy.  
NSES = National Science Education Standards.  
NAEP = National Assessment of Educational Progress for 2009*
# 1 Teacher Supplement

INTRODUCTION TO TEMPERATURE MYSTERIES

Objectives and Resources

Lesson Objectives: Learners should be able to:

6. Describe how earth’s temperature varies with location (latitude).
9. Describe how earth’s temperature varies with time of year (seasons).

Lesson Resources:

Notebooks/pencils/colored pencils

LARGE FLAT COLOR MAP OF THE AMERICAS (1 per classroom)

Color Coding:

BLACK: general text (BOLDED for essential points)
BLUE: action notes for teachers
GREEN: student inputs - spoken, written, drawn (students may fill in as they go)
RED: outline topic and approximate timing
Lesson # 1  –  [~10-15 min]
WELCOME to this unit about light & temperatures on earth!

Two of the mysteries that have intrigued people since ancient times are related to temperatures at places on the earth.

1) Firstly, travelers noticed that temperatures seemed to be different from place to place, even at the same time of year.
2) Secondly, stay-at-homes noticed that temperatures varied with time of year, even at the same place.

Of course this was very useful to know… but why these strange variations of temperatures on earth? How could it be explained? Perhaps the only clue they had to go on was that light from the sun falling on the ground seemed to heat it up. But even if this had something to do with it, why all the variation? Two real mysteries!

Let’s look more closely at each mystery.

STUDENT EXPERIENCES What’s the coldest place any of you have ever traveled? [sharing time] What is the hottest place any of you have ever traveled? [DISCUSS …coldest? hottest?]

So, let’s look on this map to find some of those places… [Do this, students may help… note how far north or south… what time of year. Some “coldest” & “hottest” may be in different places… some may be in the same town, at different times!! Point out this distinction between travel tales or stay-at-home stories, or if it does not come forth, you may offer your own examples].

Our MYSTERY No. 1 is THE TRAVELER’S TALE
Let’s imagine ourselves on a trip…

[Refer to PHOTOS] Picture this… it is the month of MARCH. We travel from Hudson Bay, Canada, down to Miami, Florida. And this is what we notice about each place….
That Canada is very cold … and Florida is very warm. Wow! Quite a difference in climate! That’s why birds (and often, people) travel south for the winter . . . or at least for Spring Break!

What would give rise to such different temperatures in different locations at the same time of the year? Most importantly, what is the science behind it?
# 1 - INTRODUCTION TO TEMPERATURE MYSTERIES

**WELCOME**

1) **Travelers’ Mystery** - Temperatures are different in different places, even at the same time of year.

2) **“Stay-at-Home’s” Mystery** - Temperatures are different at different times of year, even at the same place.

**MYSTERY NO. 1 - THE TRAVELER’S TALE**

It’s March, and we travel from Hudson Bay, Canada down to Miami, Florida... Here’s what we notice about each place...

*Hudson Bay, Canada* - cold . . . brrr!

*Miami, Florida* - warm . . . whew!

**WHY IS THE TEMPERATURE SO DIFFERENT?**
Next we check out **Mystery No. 2: The “Stay-at-Home’s” Story**

Now picture this...
We live in (or near) Chicago, and we stay at home all year ’round. What do we notice as the year goes by?

Look at the changing scene at one spot in Chicago as we pass through one year…

[Refer to Photos] Has anyone ever been down to Millennium Park? What time of year was it? What was the weather like?

(discussion with students…)

Wow! Quite a difference over the seasons, even in the same place!
But what causes this variation? What would give rise to such different temperatures at different times of the year, in the very same place? And once again, most importantly, what is the science behind it?

It took many centuries to solve these two mysteries that we’ve just discussed… and it will be our task to tackle them in this unit, with the help of a little science.
MYSTERY NO 2:  THE "STAY-AT-HOME'S" STORY
We live in Chicago... and we stay at home year round. 
This is what we notice as the year goes by...

Chicago, Illinois

June (summer)
- warm . . . whew!

December (winter)
- cold . . . brrr!

Over four seasons...
ABOUT LIGHT

Objectives and Resources

Lesson Objectives: Learners should be able to:
1. State that light carries energy, and describe simple ways to show this.
2. State how light energy received on a surface depends qualitatively on angle, on distance and on duration. Design and describe simple ways to demonstrate each dependency.
5. Explain that virtually all energy on the earth’s surface comes from the sun and that sunlight warms the earth’s surface.
16. Represent physical systems and behavior by geometrical diagrams and sketches.
17. Relate a change in one quantity to a change in another.
19. Explain that scientific questions are answered by gathering and analyzing evidence and using scientific knowledge and principles.
20. Use appropriate tools and techniques to gather, analyze and interpret data.
22. Explain that models are not the real thing but are devised to represent features of a real thing or process, to enable us to understand and make predictions about the real thing.

Lesson Resources:
Notebooks/pencils/colored pencils
Maglites (1 per class)
Fresh Batteries for maglites
Strings (colorful, several spools per class)
Paper plates with “string rays” (1 per group)
Bin for strings/spools 1 per class
Cardboard shapes to block light (shadowmaker)
Source/target for parallel string demo (aluminum pie plates with scotch tape)
Heat lamp, flood lamp or spot lamp 1 per group, plus spare
Lamp stands or sockets, e.g. goose neck 1 per group
Stopwatches (1 per group)
Card thermometer (e.g. fish tank or room thermometer, color change, 2 per group)
[Alternative: regular thermometer taped to black card. 2 per group]
Sequential Pieces of Poster (Tool Kit – “Properties of Light”)

Color Coding:
BLACK: general text (BOLDED for essential points)
BLUE: action notes for teachers
GREEN: student inputs - spoken, written, drawn (students may fill in as they go)
RED: outline topic and approximate timing
Lesson # 2  – *(About light~55-65min)*

As people wondered about the mysteries of all these strange variations of temperatures on earth, we looked for explanations. It took many centuries to solve the puzzles, with the help of science, and we will show you the solution in this unit.

After making observations at the scenes and finding clues, scientists decided that sunlight upon the earth was a major “suspect” as the cause for the temperature variations that we notice. They have been able to solve these mysteries by developing and using a TOOL KIT of scientific knowledge, especially about light, but also about the geometry of the earth and sun.

Today we’ll see what they found out about light, and how it applies to solving these mysteries.

*Properties of Light (15-20min)*

[The room is dark … A maglite is then turned on.] It may appear to us that light is simply present instantaneously in the room when the light source is switched on, filling space like air, but scientists discovered that light takes time to TRAVEL out from the source, in straight lines, in all directions.

Let’s check out these properties of light. [Block the light with your hand/(cardboard shape), and ask the students to describe what they see - shadow.] Ok, from this observation we can infer that light travels in straight lines, in all directions. [ask the students to describe the shape of the shadow compared with the shape of your hand, and how the light must have traveled to make such a neat copy behind the object…]

We can model this with STRINGS, which will represent how the light “rays” traveled from the source in straight lines toward the board. [Have volunteers help use a few STRINGS to model light coming from the source… going all the way to the edges of the shadow in straight lines, touching the edges of the blocker, no matter where on the edge of shadow you stretch the strings.] Our string model is obviously not made out of light, it just helps us to understand some features and behavior of light as it travels. You can see that the light went in all directions, forming a complete shadow where it was blocked, but lighting up the rest of the board too. It’s also traveling to the eyes of everyone in this room, otherwise you wouldn’t be able to see it! All directions! Except where blocked.

*Models of Light, ~ 10 min*

We can picture a simple model that will show all of these properties of light

[Teacher draws POINT SOURCE, with diverging rays … explains how each property is portrayed in model.] We are going to turn this light into a street light… Let’s show the ground underneath, [draw line below] and connect some of our rays all the way to the ground (straight, remember!)

But…if instead of a nearby street light, it’s a bright light about 92 million miles away … its rays will be hitting the ground almost parallel to each other as in THIS picture, our model of “how sunlight hits the earth.” [Teacher draws parallel rays hitting the ground.]

Now we’ll use some strings as light rays to model how light travels from a source to a surface, whether near or very far away. Fun simulation with long strings attached to target, one kid can “BE” holding rays/strings at the “source,” another holds target with strings attached, radiant effect very close, moves farther and farther away ... Students observe that rays become more and more parallel (justifies/clarifies our repeated use of parallel ray model for sunlight upon the earth!)

... So we see the rays will be hitting the target almost parallel to each other....So our drawing of parallel rays is a good one, to represent light from a distant source.
SOLUTIONS TO OUR MYSTERY QUESTIONS...

After making observations ...

After finding clues/evidence ...

Sunlight became a “major suspect” for temperature variations on earth.

BASIC TOOL KIT of scientific knowledge about LIGHT...

<table>
<thead>
<tr>
<th>Properties</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIGHT TRAVELS . . .</td>
<td></td>
</tr>
<tr>
<td>1) . . . out from a source</td>
<td>light can be blocked (shadows)</td>
</tr>
<tr>
<td>2) . . . in straight lines</td>
<td>shadows take shape of objects</td>
</tr>
<tr>
<td>3) . . . in all directions</td>
<td>light goes to every eye in room!</td>
</tr>
</tbody>
</table>

MODELS OF LIGHT

SOURCE + LIGHT UPON A NEAR SURFACE   LIGHT UPON A DISTANT SURFACE
Another very interesting and important thing about light is that it carries energy!!!

Sometimes energy is in the form of heat. Most of the energy on the earth’s surface comes from sunlight, so this light energy is very important to us (that’s why we need to understand light & energy to solve our mysteries!)

Let’s bring up some examples of light carrying energy…

Feel it on your skin, etc. sunbathing
Blacktop gets hot on summer day
Hot sand at the beach
Restaurant food under heat lamps
Magnifier can start fire
Plants use light energy… photosynthesis!

We’ll now demonstrate that light can carry energy, by finding some evidence to back it up. We can shine light on a few things and see if they get warmer.

Let’s verify this property using a lamp and our hand. (These lamps can get pretty hot, so please do not touch them directly with your hands!) (SAFETY)

When we hold our hand about a foot away from the lamp, we experience the heating effect of the light … (HOT) Is this evidence for light carrying energy? (YES)

Now we’ve said that it “feels like” light carries energy, but we can also do a more scientific measurement to verify this property of light. Let’s use these lamps again, and do a verification of the heating effect of light shining on these card thermometers.

When we deal with scientific measurements, we express quantities using numbers and units. For temperature, which is the degree of hotness or coldness measured on a definite scale, the common units in the US are degrees Fahrenheit. In science we most often use degrees Celsius. Both are found on your thermometers …

Let’s see what happens when we hold a thermometer fairly close to the light and compare the difference in temperature between when the light is turned off and when it is turned on. (the temperature reading goes up) Is this more evidence for light carrying energy? (yes) [Teacher explains how to read thermometer if needed]
LIGHT CARRIES ENERGY AND HEATS THINGS UP

Importance:

Most of the energy on the earth’s surface comes as light from the sun

(that’s why we need to understand light & energy to solve our mysteries!)

Examples:

Feel it on your skin, sunbathing, blacktop gets hot on summer day, solar cells,
chlorophyll/plants, food heat lamps, magnify to heat and burn leaf… etc.

VERIFICATIONS:

1) Lamp and hand

Experience:  ___________________________ Hand gets warm

Is this evidence that verifies "light carries energy"?  _______Yes_________

2) Lamp and card thermometer

Measurement:  ___________________________ Temperature reading goes up

Is this evidence that verifies "light carries energy"?  _______Yes_________
So we have verified that light energy can increase temperature. Let’s learn more about that process. The amount of light energy received depends on three factors ... the duration/length of time the light is received, the distance from the source, and the angle that the light strikes the surface.

To do a careful, scientific investigation of the effect of these factors, time, distance, and angle, we look at them “one at a time.” To do this we’ll keep everything else the same, and change/vary only one thing, and we’ll see what difference that one change makes. This is called the method of “Control of Variables” and scientists use it often.

Let’s test the effect of time first. Test it out carefully with your hand first, holding it at a particular distance for a short time, and then for a longer time. [there is no need for specific time measurement... have them record longer time/hand gets warmer]. After you record your simple observation/evidence, then use the thermometer cards and stopwatches for a more quantitative test [STUDENTS DO THIS.... Teacher assisting as needed] longer time/temperature gets higher

Is our statement verified? (YES, more light energy is received in a longer time).

Next we’ll test the effect of distance.

Hold your hand in the light beam first near, and then farther away, for about the same amount of time on the clock (straight on to the lamp/light beam). See which feels hotter. Record your observation (farther light, less heat on hand)

Repeat this distance test by conducting a “temperature race” with the card thermometers, one near and one farther, recording temperature readings and which one gets hotter faster. (farther light, lower temperature)

Is this evidence verifying our statement? (Yes, less light energy is received when source is farther from the surface).
# TIME, DISTANCE, & ANGLE AFFECT LIGHT ENERGY RECEIVED

## EFFECT OF TIME:

**STATEMENT:** More light energy is received during a longer amount of time.

**VERIFICATIONS:**

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>_______</td>
</tr>
<tr>
<td>10</td>
<td>_______</td>
</tr>
<tr>
<td>20</td>
<td>_______</td>
</tr>
</tbody>
</table>

Evidence: longer time, hand gets warmer, temperature gets higher

Is the statement verified? **YES**

## EFFECT OF DISTANCE:

**STATEMENT:** Less light energy is received when a light source is farther away.

**VERIFICATIONS:**

<table>
<thead>
<tr>
<th>Approx. distance (cm.)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>_______</td>
</tr>
<tr>
<td>20</td>
<td>_______</td>
</tr>
</tbody>
</table>

Evidence: farther light, less heat on hand, lower temperature

Is the statement verified? **YES**
Now we'll test the effect of angle.

Hold your hand in the light beam, first head-on (perpendicular), then at a slant/tilt, both times at the same particular distance from the light (source), and for about the same amount of time. See which feels hotter. Record your observation (Hotter with hand straight on, cooler with hand more tilted)

We'll also do a more quantitative test of angle effect. It involves another “temperature race” with two card thermometers next to each other, one head-on to the light, the other angled (both at the same distance), and watch them after you turn on the light beam.

Read and record the temperatures, and see if the quantitative test verifies/confirms the statement that the more straight on (directly) that the light strikes a surface, the more the heating effect. (Yes, more tilted, lower temperature)

Do these results verify our statement? (Yes, less energy is received when light comes to surface at more of a slant...) (a smaller angle between incoming light and the surface)

SUMMING IT UP ~ 5 min:

We learned today that light travels and carries energy, and that it has a heating effect on surfaces that it strikes. (refer to “properties of light” poster)

We have verified that the heating effect from light depends on THREE FACTORS ... TIME, DISTANCE, and ANGLE.

The longer the TIME, the more the heating effect.
The longer the DISTANCE, the less the heating effect.
The bigger the ANGLE, the less the heating effect.

(Note to teacher... it depends upon other things as well, but they're less relevant to the particular case of sunlight's direct effect on climate, so it's not necessary to mention properties of source, surface, medium, etc. unless questioned).
**EFFECT OF ANGLE:**

**STATEMENT:**  Less light energy is received when incoming light is more slanted.

**VERIFICATIONS:**

<table>
<thead>
<tr>
<th>Experience with hand</th>
<th>Measurement with thermometer card</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Hand" /></td>
<td><img src="image2.png" alt="Thermometer Card" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same distance - Head-on (straight-on)</td>
</tr>
<tr>
<td>Same distance - Slanted (tilted)</td>
</tr>
</tbody>
</table>

Evidence: __________ more tilted, cooler hand, lower temperature________

Is the statement verified? __________ YES___________________________

**SUMMING IT UP...**
# 3 Teacher Supplement

**INTRODUCTION TO TEMPERATURE MYSTERIES**

**Objectives and Resources**

**Lesson Objectives:** Learners should be able to:
3. Explain why the intensity of surface illumination depends on angle, and compare cases (by considering area illuminated by a beam).
4. Explain why intensity depends on distance for a diverging light beam (by considering area illuminated by a beam).
15. Determine area by counting small squares within a given outline.
16. Represent physical systems and behavior by geometrical diagrams and sketches.
17. Relate a change in one quantity to a change in another.
18. Use mathematics in aspects of scientific inquiry.
19. Explain that scientific questions are answered by gathering and analyzing evidence and using scientific knowledge and principles.
20. Use appropriate tools and techniques to gather, analyze and interpret data.

**Lesson Resources:**
- Notebooks/pencils/colored pencils
- Overhead projector (1 per class)
- Card with square hole in it for overhead projector (different size holes for different projection circumstances)
- SPRAY to reveal projector beam (*as in lab)
- Giant graph paper (pad per room, OfficeMax)
- String/tape
- Flashlights (1 per group)
- Rubber bands
- Meter sticks and rulers (1 per group)
- Protractors (1 per group)
- Masking tape
- 4 lasers in a square frame (1 set per class)

**Color Coding:**
- **BLACK:** general text (BOLDED for essential points)
- **BLUE:** action notes for teachers
- **GREEN:** student inputs - spoken, written, drawn (students may fill in as they go)
- **RED:** outline topic and approximate timing
Lesson # 3  – (~70-75 min)
(review ~5min) Let’s review from yesterday. We found out that light travels, and that as it
strikes (shines on) a surface, it provides (carries, brings) energy that heats the surface.

We learned that the amount of heating is related to the amount of time that the light is
being received, also to the angle at which the light strikes the surface, and also to the
distance between the light source and the surface.

Regarding the time factor, it makes sense that the longer there is energy heating up a
surface, the hotter it will get. For example, you don’t want to spend too long under the hot
sun or you may overheat. Any other examples?

Now let’s explore why two other factors, angle and distance, make a difference to the
heating effect of light on a surface.

The reason that the angle at which light energy hits a surface makes a difference is that at
greater angles, the same amount of light energy is ‘spread out’ over a larger area, it is less
“concentrated,” resulting in less brightness, less “intensity.” (and vice versa)

[LIGHT PROJECTOR DEMO, ~15-20 min]

To demonstrate this we will use a square light beam (from a projector) striking a screen
(board/wall) at different angles. To keep the same distance between the light source and the
screen (remember this important aspect of controlling variables method), we will connect the
projector to the screen by a string so that it can revolve around it in a semi-circle (all the
while pointing at a particular spot).

Make square beam of light using card with square hole & overhead projector. Point beam
directly at the board/screen, along a perpendicular line. Trace the lit square area on the
board (shown in GREEN front view). Move the projector from perpendicular (to the screen) to
slanted, keeping the same distance. Trace the new shape (a rectangle, shown in blue front
view) on the board, with same left side as the [green] square. Show Diagrams of Top Views
above both of these Front View tracings of the lit areas. Discuss this model of the light beam
and how it corresponds with (and explains) our observations of extended width (and thus, area)
at a greater angle. NOTE: Extended BLUE shape will not be perfectly rectangular, because
this is actually a diverging beam of light, but it still shows the angle effect quite well.

Do our observations verify our statement? [YES, lit part is bigger/wider/longer for slanted
case, has a greater area, and less brightness.]
**REVIEW**

Light travels in straight lines and carries energy.

Time … Angle … Distance – factors in heating effect of light striking a surface

**WHY HEATING EFFECT DEPENDS ON ANGLE**

Statement:
When light strikes a surface at more of a slant, the same amount of light spreads out over a larger area, resulting in less light per unit of area, less brightness, less “intensity.”

Qualitative Demonstration: “Light Projector”

Setup: Use a light projector with a square beam shining on a screen from the same distance away but from different angles.

<table>
<thead>
<tr>
<th>OBSERVATIONS</th>
<th>Head-on (straight-on)</th>
<th>Slanted/(tilted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>square</td>
<td>rectangle … BIGGER AREA</td>
</tr>
<tr>
<td>Brightness</td>
<td>bright</td>
<td>DIMMER</td>
</tr>
</tbody>
</table>

Diagrams:

model of top views…

slanted/tilted

model of front views (on board)...

Statement verified? ___________________ YES ___________________
Taking measurements: Flashlight-on-a-stick.

We saw “by eye” that the lit/illuminated area got bigger as the angle got more slanted, but now we need something more accurate. We’ll take some measurements to verify our statement quantitatively.

[Quantitative verification, ~ 25 min]

Setup:
Use a flashlight taped to a meter stick, shining down on a sheet of paper with a grid of squares.

Outline the bright spot on the paper with a pencil.

Determine the area within the outline by counting the number of squares that are lit.

Do this at three different flashlight angles.

The flashlight “beam” of light carries the same amount of light energy in each case. This experimental method allows us to calculate the area covered by that light beam at different incoming angles (SAME DISTANCE!!!), and we can see quite clearly that the light/energy is more or less “concentrated.”

Students complete Flashlight-on-a-stick verification with assistance from teacher, who will guide toward relevant answers.

Ask students if this activity helped them verify the statement that explained the angle effect on light/energy upon a surface. (hopefully…. YES )
**Quantitative Verification: “Flashlight-on-a-stick”**

**Setup:** Flashlight taped to a meter stick, shining down on a sheet of paper with a grid of squares.

Outline the lit region and determine its area at three different angles.

**Data table:**

<table>
<thead>
<tr>
<th>Angle of light beam to paper (degrees)</th>
<th>Observed brightness</th>
<th>Area lit by light beam (number of lit squares)</th>
<th>Fractional amount of light beam on each lit square</th>
</tr>
</thead>
<tbody>
<tr>
<td>90° (straight-on)</td>
<td>Brightest</td>
<td>. . .</td>
<td>. . .</td>
</tr>
<tr>
<td>45° (slanted)</td>
<td>less bright</td>
<td>. . .</td>
<td>. . .</td>
</tr>
<tr>
<td>20° (very slanted)</td>
<td>least bright</td>
<td>. . .</td>
<td>. . .</td>
</tr>
</tbody>
</table>

From the same beam of light energy, when the light comes in more slanted, what happens to the fraction of light energy which is received by each small square (unit of area)? __________ it gets smaller_______________________________

This fraction represents the brightness/intensity of light on a surface... which is directly related to the heating effect of light energy.

**Heating effect** of light on a surface is____ smaller____ if light comes in more slanted.

Does our data help explain why the heating effect of light depends on ANGLE? **YES**
Next let’s think about why the distance from the light source to the surface influences the heating effect. It’s actually quite similar to the explanation regarding the influence of angle. When the distance is greater, and light rays diverge from a source, the same amount of light energy gets ‘spread out’ over a larger area, becoming less “concentrated,” resulting in less brightness, less “intensity.”

[Qualitative Demo, ~5 min]

To demonstrate this we’ll first use that square light beam again (from a projector) shining on a screen/wall/board head-on, starting from near and gradually moving farther away.

[Again, make square beam of light using card with square hole & overhead projector and watch the transformation of the lit area as it becomes bigger and dimmer with distance from source, trace small and larger squares on the board, students copy on page 4 “front views”]

Let’s sketch the front views of what we see… then fill in our tables with a verbal description.

[fill in the TABLE, as shown in GREEN]

The reason this area gets bigger is because this light is actually diverging from the source, and it diverges more the farther it travels to the surface… let’s make light “visible” to see this effect.

[spray onto projector beam to see beam of light, and then sketch MODEL of SIDE VIEWS… Discuss the area expansion resulting from greater distance. These “rays” are not really parallel... remember our early models of light reaching the ground, first from nearby (diverging) and then from afar, seeming more parallel the farther the source]

So we see that the lit part of the surface has a larger area, and the light spreads out and grows dimmer, when the distance becomes greater between source and surface. Did we verify our statement? [YES, lit part is bigger and dimmer for greater distances.]

[Qualitative verification ~ 10 min]

One more check with a handy-dandy “Flashlight-off-the-stick”

Here again we can see “by eye” that the lit/illuminated area gets bigger as the distance gets bigger, verifying our statement once more. No measuring necessary ... you get the point.

Have students complete their page (observation, effect of distance on heating, and conclusion).

In summary, Time, Angle, & Distance are factors in the heating effect from light energy striking a surface. Today we paid closer attention to angle and distance, and learned that with greater angle of incoming light, and greater distance between source and surface, the same amount of light spreads out over a larger area, resulting in less brightness, less light “intensity” on the surface ... and thus, a smaller heating effect.

Optional challenge application (10 minutes):

Remember our little demonstration of the fact that, at great distances, the light rays striking a surface from a source get closer to being parallel. Pose the question of whether or not distance would matter to intensity if our rays of light upon the surface were not divergent, but were truly parallel like we showed in our yesterday’s model of light from a distant source. We can push our thinking to that extreme, imaginary case, of a set of perfectly parallel rays, and possibly even test 4 laser pointers fixed into a square frame. The resulting projected square would never change size no matter how great the distance between source and “screen.”

The deeper but quite challenging understanding that this offers is that the closer the incident rays are to being parallel, the lesser the impact of changes in distance upon incident light energy and heating effect on a surface. This relates distance effects to a ray model, just as we relate angle effects to a ray model elsewhere.
**WHY HEATING EFFECT DEPENDS ON DISTANCE**

**Statement:**
When diverging light rays strike a surface from a greater distance, the same amount of light spreads out over a larger area, resulting in less brightness, less “intensity.”

**Qualitative Demonstration: “Light Projector”**

**Setup:** Use a light projector with a square beam shining on a screen head-on, starting from near and gradually moving farther away.

<table>
<thead>
<tr>
<th>OBSERVATIONS</th>
<th>Near</th>
<th>Far</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Square</td>
<td>Square-BIGGER AREA</td>
</tr>
<tr>
<td>Brightness</td>
<td>Bright</td>
<td>DIMMER-LESS Bright</td>
</tr>
</tbody>
</table>

**Diagrams:**

- **front views:** near/green far/blue
- **model of side views:**

**Statement verified?** __________ YES

**Qualitative Verification:** “Flashlight-off-the-stick”

**Setup:** Use the flashlight again, shining directly down (head-on) to a sheet of paper with a grid of squares, starting from near and gradually moving farther away.

Outline the lit region for both near and far cases, and compare the area lit.

**Observation:** _farther--bigger area--dimmer_

**Heating effect** of light on a surface is __less_____ if light source is more distant.

Does our data VERIFY that when diverging light rays strike a surface at a greater distance, the result is less “intensity” of light energy on that surface? _____YES_______
# 4 Teacher Supplement

TEMPERATURES VARY WITH LOCATION

Part 1 – View from the ground

Objectives and Resources

Lesson Objectives: Learners should be able to:

6. Describe how earth’s temperature varies with location (latitude).
7. Describe and compare the apparent (observed) motion of the sun in the sky from different locations on earth.
8. Explain why average temperatures vary with latitude on earth. Do this from ground-based viewpoint (in terms of different angles of sunlight to the ground).
13. Show how basic principles of science and math apply in real world situations
16. Represent physical systems and behavior by geometrical diagrams and sketches.
17. Relate a change in one quantity to a change in another.
19. Explain that scientific questions are answered by gathering and analyzing evidence and using scientific knowledge and principles.
20. Use appropriate tools and techniques to gather, analyze and interpret data.
21. Think critically and logically to make relationships between evidence and explanations. Distinguish between observations and inferences.
23. Use models to explain and predict phenomena.

Lesson Resources:
Notebooks/pencils/colored pencils
Column thermometer 1
Portable spotlight 1
Spare battery
Items for Canada, Kalamazoo, and Florida rows, location & temp. signs, etc.
Fabric/blinds (for windows, dim light)
Posters of sunrise, sunset (with time of each… 7am, 7pm)

Color Coding:
BLACK: general text (BOLDED for essential points)
BLUE: action notes for teachers
GREEN: student inputs - spoken, written, drawn (students may fill in as they go)
RED: outline topic and approximate timing
Lesson # 4 - (~70-75 min)

[Review 5 min]

We have learned some basic science knowledge about light... that light energy can heat a surface, and the heating effect depends on the amount of time (duration) that the light is being received, on the distance between the light source and the surface, and also on the angle at which the light strikes the surface.

Remember that there are two mysteries regarding temperatures on Earth that have puzzled people for a very long time.

**MYSTERY NO.1 is the Traveler's Tale** - Temperatures vary with location on Earth.

**MYSTERY NO.2 is the Stay-at-home's Story** - Temperatures vary with time of year.

Our new knowledge about light is going to help us understand the solutions to these mysteries.

We'll start with the mystery of the TRAVELER'S TALE (~ 10 min)

The scenario is a journey...

It was the month of March. Time for a Spring Break vacation!

A family living in Canada (by Hudson Bay) started out on a long drive. They stopped along the way in Kalamazoo, Michigan (by the Great Lakes) to visit friends. Then they continued on to Miami, Florida to stay with some relatives.

When they set out from Canada it was bitterly cold; as they traveled, they noticed that it seemed to get warmer and warmer.

During the trip, they took photographs and recorded the temperatures at each location... let's look at these...
# 4 - TEMPERATURES VARY WITH LOCATION

Part I - View from the Ground

**REVIEW**

Light energy can heat a surface, and the effect depends on time, distance, & angle.

**BACK TO OUR TEMPERATURE MYSTERIES!!**

**MYSTERY # 1 - Traveler's Tale -**
Temperatures vary with location on Earth.

**MYSTERY # 2 – Stay-at-home’s Story -**
Temperatures vary with time of year.

**MYSTERY #1 - Part I - VIEW FROM THE GROUND**

**The Travelers’ Tale**

It was the month of **March**. Time for a Spring Break vacation! A family living in **Canada (by Hudson Bay)** started out on a long drive.

They stopped along the way in **Kalamazoo, Michigan** (by the Great Lakes) to visit friends. Then they continued on to **Miami, Florida** to stay with some relatives. As they traveled, they noticed that it seemed to get **warmer and warmer**.

(*During the trip, they took photographs and recorded the temperatures at each location...*)
Every location has its midday temperature listed on your page, and we need to indicate them on the thermometers shown. Here’s an example of this type of thermometer. [Show thermometer to the class… Discuss how to read temperatures on such instruments, see what the ROOM TEMPERATURE is. Guide students toward reasonable depictions of how the given readings would look on these sketches of thermometers (if needed, may use transparency or board to depict three thermometer readings)]

Clearly, the travelers experienced very different temperatures along their trip. They were able to describe the differences not only by saying that it got “warmer,” but also by measuring and reporting accurate values of the temperature in each location.

The question is, if the whole surface of the earth receives most of its energy as light from the sun, why is there so much variation in temperatures at different locations on Earth?

**CSI REPORT (~ 15 min)**

Well, let’s imagine a scientific team called the CSI team – the “Climate Scene Investigators.” They visited each scene to gather clues and collect evidence (as scientists do). From their observations, they were able to make some strong inferences, and draw conclusions about the observed temperature variations in terms of the science of light that we’ve been discussing... let’s look at this “READY-MADE SCIENCE.”

The CSI team concluded that the major cause/culprit for different temperatures at different locations is the difference in ANGLE of incoming sunlight, and that the time (duration) and distance from the source were not apparent causes.
Travelers’ experiences:

HUDSON BAY, CANADA
Temperature 0°F

KALAMAZOO, MICHIGAN (GREAT LAKES!)
Temperature 32°F

MIAMI, FLORIDA
Temperature 70°F

The CSI team - CLIMATE SCENE INVESTIGATORS - Gathered clues . . . collected evidence . . . explained !!!

“READY-MADE SCIENCE”
Temperatures vary with location because...
We should take a careful look at the evidence in their report, and see if their conclusions seem justified.

[Point out that the report includes various kinds of information and discuss each type of data... some is numerical, like temperature and time, some is descriptive and qualitative, and some is pictorial/graphical.]

Within the first column, we find numerical evidence to confirm the temperature variation with location, as the travelers reported.

From the CSI team’s observations of 12 hours of daylight in each location, we can infer that the time factor, being exactly the same in each location, cannot account for the observed differences in temperature.

The distance variable can also be ruled out. The sun appears about the same size (not bigger or smaller like things that are closer or farther away). Therefore, based on observation of the size of the sun, we infer that it’s the same distance away from each location. [if needed, discuss examples like photo images of closer objects/people appearing LARGER, farther things appearing SMALLER (especially thru one eye!).]

Let’s look at the pictures in the second column. We see the view of the Midday Sun in each location... and how high it is above the horizon. Notice that in Canada, the sun is much lower. In Miami, the sun is the highest relative to the horizon. [Note: the difference in height has been somewhat exaggerated to make the point] (SAFETY NOTE: never look directly at the sun)

The scientists have used the height of the sun in these middle pictures to help them figure out how to draw the Ray Diagrams that represent (or MODEL) the angle at which the light must have been coming from the sun toward the ground. The lower the sun is in the sky, the more slanted the rays come toward the ground. Remember that they are showing the rays as parallel because the sun is so far away.

Next we’ll do a simulation that will help us decide whether this makes sense to us, and whether we agree with the CSI team’s claim/conclusion regarding angle of light.
CSI REPORT FROM THE SCENE ON THE GROUND...

CONCLUSIONS:
The cause/culprit for DIFFERENT TEMPERATURES at different locations is the DIFFERENCE in ANGLE of incoming sunlight. Time/duration & distance are not apparent causes, and will not be held responsible.

EVIDENCE:

<table>
<thead>
<tr>
<th>Location</th>
<th>Temperature</th>
<th>Day duration</th>
<th>Midday Sun:</th>
<th>Ray Diagram:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hudson Bay, Canada</td>
<td>0° F</td>
<td>12 hours</td>
<td>Apparent Size - usual</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Elevation - low</td>
<td></td>
</tr>
<tr>
<td>Kalamazoo, Michigan</td>
<td>32° F</td>
<td>12 hours</td>
<td>Apparent Size - usual</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Elevation - higher</td>
<td></td>
</tr>
<tr>
<td>Miami, Florida</td>
<td>70° F</td>
<td>12 hours</td>
<td>Apparent Size - usual</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Elevation - highest</td>
<td></td>
</tr>
</tbody>
</table>

Midday Sun (as seen) [Ray Diagram (as imagined from right side)]

*Never look directly at the sun*
(CHAIRS ON LOCATION ~25-30 min) We can take a ground-based viewpoint right here in our classroom. We’ll act as observers on the ground, looking out at the sky.

Let’s line up three rows of chairs ... representing the three locations from our Traveler’s Tale. We’ll place the rows of chairs with the back row as the Hudson Bay area in Canada (the travelers’ home)... and the middle row as Kalamazoo, and the front row as Miami which is the farthest south.

[Divide the class in 3 groups (join two small groups/tables) to do this activity. Ask the students to sit down on the chairs . . . and watch.]

Now imagine that you are truly sitting outside in the location that your row represents, and the room all around us is the sky.

The sun is about to rise! [Dim the lights... switch on and shine the bright spotlight beam at the bottom of the wall to the left side of the Miami row]

Ah we have a beautiful sunrise dawning in the east [POSTER] slowly moving across the sky as we gaze up at it. It reaches a maximum midday elevation when it is right in front of each of us, and then it slowly sinks down toward the western horizon, making a beautiful sunset [POSTER] before hiding away on the other side of Earth.

[Repeat this process, BUT this time instruct the students to point toward the sun with their hands as it traces its path across the sky stopping when the sun is directly in front of them (midday position). Ask two students from each row (maybe the two students from the west end) to stand up over on the west side, observe and sketch the angle of the arms as they point toward the midday sun. These students will be the "evidence sketchers".

→ Have the students SWITCH ROWS, and repeat the process quickly, so that everybody can experience the difference in angle between each location! When done, have the reporters display their sketches on the board, discuss and ask students to draw arms at suitable angles.]

By the way, as you pointed at the sun at a certain angle, the rays from the sun were coming toward you at that very same angle!!! [Work toward everyone drawing a few appropriate parallel rays that represent the angle at which the sun came toward them at each row/location, as shown in green.]

Hey! Check back a page and see if your drawings look like the CSI Ray Diagrams for each location?! (YES, THEY DO)

Do we agree with the CSI claims based on the “view from the ground”?  YES
Let's **simulate** the situation at each location, and **verify** for ourselves the conclusions of the CSI team.

**Modeling ground-based observations**

Three rows of observers on the ground... at three locations as shown...

A simulation of the sun's distant path across the sky, checking angle of sun in the middle of the day.

| Hudson Bay, Canada | Kalamazoo, Michigan | Miami, Florida |

Do our diagrams match up with the CSI Ray Diagrams for each location?  ____**YES**____
(SUMMARY ~ 5 min)
So our simulation helped us confirm the CSI interpretation that the more slanted the incoming light, the lower the temperature. This is in perfect accord with the science of light. Recall that we learned that the more slanted the light, the less the light intensity upon a surface, and the less the heating effect. The reason for this is because the same amount of light energy has to spread out over a larger area on the surface when it hits it at more of a slant (when light rays form a smaller angle with the ground).

Regarding the 1st TEMPERATURE MYSTERY, our “view from the ground” indicates that differences in ANGLE of sunlight upon the ground cause temperature to vary with location! (Climate!) The other two factors, duration of daylight and distance from the sun, do not seem to be factors (at least at this time).

[It’s not necessary to bring up the following, unless asked… but the duration of daylight certainly does influence temperature… causing more warmth in the summer months. This, however, is related to seasons rather than climate… because in any one location, the total number of daylight hours evens out over the course of a year]

Next Monday, we’ll have a bit more adventure… with a “View from Space”!!

APPLICATIONS ~ 10 min
Discuss the control of variables… this could get interesting.
Do we agree with the CSI conclusions based on the “view from the ground”? **YES**

According to a “view from the ground,”
Mystery # 1, “Why does temperature vary with location?”
has been SOLVED!

The main culprit is ____ANGLE____
APPLICATIONS -

Joe and Sarah play games

1) Joe is one of the travelers. In Canada, both he and his neighbor Sarah have identical solar-powered gaming systems, that recharge from a solar panel that rests flat on the ground. Joe takes his system with him on his trip.

Sarah partially charges up his system for 4 hours in the sun in Canada.
Joe partially charges up his system for 4 hours in the sun in Miami.

A. Both game systems will end up with the same amount of charge.
B. The system in Canada will have a greater charge.
C. The system in Miami will have a greater charge.
D. We cannot make a prediction based only on this information.

Explain your reasoning...

2) After using up all the power in both systems, playing their favorite games...

Sarah partially charges up her system for 4 hours in the sun in Canada.
Joe partially charges up his system for 2 hours in the sun in Miami.

A. Both game systems will end up with the same amount of charge.
B. The system in Canada will have a greater charge.
C. The system in Miami will have a greater charge.
D. We cannot make a prediction based only on this information.

Explain your reasoning...
TEMPERATURES VARY WITH LOCATION/LATITUDE
Part 2 – View from Space

Objectives and Resources
Lesson Objectives: Learners should be able to:
3. Explain why the intensity of surface illumination depends on angle, and compare cases (by considering area illuminated by a beam).
6. Describe how earth’s temperature varies with location (latitude).
8. Explain why average temperatures vary with latitude on earth. Do this from both ground-based and space-based viewpoints (in terms of different angles of sunlight to the ground).
13. Show how basic principles of science and math apply in real world situations
16. Represent physical systems and behavior by geometrical diagrams and sketches.
17. Relate a change in one quantity to a change in another.
18. Use mathematics in aspects of scientific inquiry.
19. Explain that scientific questions are answered by gathering and analyzing evidence and using scientific knowledge and principles.
21. Think critically and logically to make relationships between evidence and explanations. Distinguish between observations and inferences.
22. Explain that models are not the real thing but are devised to represent features of a real thing or process, to enable us to understand and make predictions about the real thing
23. Use models to explain and predict phenomena.
24. Communicate scientific procedures and explanations.
25. Develop descriptions, explanations, predictions and models using evidence.

Lesson Resources:
Notebooks/pencils/colored pencils
Basketball (1)
Pilates ball/model
Peppercorns (50)
80 ft bright string/rope (1 piece)
Flashlights (1 per group)
Beach ball globes, small globes
Firm card stock (2 per group)
Very small dolls? (1 inch or so) (1 per group)
Portable spotlight (1)
Teacher’s Globe
Black, light-blocking fabric

Color Coding:
BLACK: general text (BOLDED for essential points)
BLUE: action notes for teachers
GREEN: student inputs - spoken, written, drawn (students may fill in as they go)
RED: outline topic and approximate timing
Lesson # 5 - (~65-75 min)

[Review~5-10 min] Let’s have a review ... last week we learned that the heating effect of light energy on a surface varies with time, distance, & angle.

We also learned the solution to our first mystery about temperature variations upon the earth due to location, in terms of the “view from the ground.”

We learned that distance was not an obvious cause/factor... the sun “seemed like” it was the same size in the sky at each location, not larger or smaller as nearer or farther objects usually are.

"Sunlight time" did not seem to be a factor for temperature variation with location, because the number of hours of daylight was the same for each location.  (true at equinoxes, and varies symmetrically over the course of a year, canceling out - need not mention unless asked)

Based on a “View from the Ground,” the ANGLE of incoming light was implicated as an important cause of different heating effects from sunlight upon the Earth ... the higher the sun in the sky, the higher the INTENSITY of light energy (and heating) upon the surface. We simulated their findings and agreed with their choice of “main suspect.”

Now we shall get back to the solution to our first mystery... because the Climate Scene Investigation (CSI) team of scientists was not satisfied with “seems like”... or with just knowing the facts that the sun was higher in the sky and the temperature warmer the farther the family traveled. They wanted another perspective, a “View from Space.” (REPORT FROM SPACE ~10 min)

So, they collected and analyzed information from Space Science Experts, and found evidence that supported ANGLE but not distance or time as likely factors in temperature variation with location. Let’s see how they came to the conclusions in their REPORT...

First, this big picture of Earth shows its SHAPE and how each location (MARKED) is lit by incoming sunlight in March. [point out locations & three different latitudes in yellow on picture... the sun is far away to the right. Remind students of the meaning of LATITUDE shown below the picture]

(NOTE: if asked, we will show and consider TILT in lesson 7... We’ve chosen March 21 and a point in space with a clear view of the equal hours of daylight and night)

The space science experts also supplied additional scientific numerical data regarding the geometry of the earth and the sun. (Discuss the data in the table... )
REVIEW

Heating effect of light energy varies with time, distance, & angle.

Regarding MYSTERY # 1, the Traveler’s Tale, the "VIEW FROM THE GROUND" indicated that ANGLE is the main suspect for causing temperature variation with location on Earth.

\[
\text{sun elevation } \rightarrow \text{ angle } \rightarrow \text{ light intensity } \rightarrow \text{ temperature}
\]

MYSTERY #1 - Part II - VIEW FROM SPACE

---CSI REPORT FROM A REMOTE LOCATION---

Climate Scene Investigation

CONCLUSIONS: Scientific “view from space” supports ANGLE, but not distance or time, as a likely cause for temperature variation on Earth due to location/latitude.

FACTS & FIGURES:

A View of Earth from Space

Sunlight Upon the Spinning EARTH

(March 21, 2007)

Note: LATITUDE is the angular distance North or South of the earth’s equator, measured in degrees
(DISTANCE ~ 15 min) The CSI team analyzed this data and drew themselves a model to clarify some relationships. [look at diagram of long rays from distant sun]. Regarding distance, the investigators found that light travels approximately the SAME distance from the sun to each location on the earth. Thus, contrary to popular belief, distance is NOT a factor in creating different climates.

It is true that during the day, the North Pole of the Earth is about 4 thousand miles farther away from the SUN than a spot on the equator. But this extra distance is completely insignificant compared to the distance from the SUN to the Earth (93 million miles). Let's check. **Hand out 1 or 2 PEPPERCORNS to each student in the class... tell them to hold onto it (no snacking!). Get out the basketball and the 80 feet length of string. I'm holding the Sun, this basketball... and guess what you all are holding in your hands... the Earth.** This is a pretty good scale model of the difference in size between the Sun and the Earth... the Earth may be even smaller than that, depending on the peppercorn.

And here I have a string that represents about how far apart they are in space. Let's try stretching it out to demonstrate how far away the "basketball Sun" must be from the "Earth peppercorn." **If you have the time and the space, preferable to go out into the hallway and have all the peppercorn kids stand in one area and one of them holds the string while the SUN (and the other end of the string walk away).** If contained in classroom, may zig-zag the string from student to student back and forth across the room. When extended to full length, then we explain that the North Pole of that Earth is half a peppercorn farther away from the sun than the equator of the peppercorn is. Wow. The extra distance is insignificant.

(TIME ~ 5 min) As far as the time/duration of daylight, the CSI team found it to play no role in climate either. As they saw the Earth rotate on its axis through a full day, each of the three locations was visibly lit up by sunlight for the exact same amount of time (12 hours). [Direct their attention to the picture of Earth on Page 1, which represents how the "rays" from the sun actually come toward the Earth at an equinox. The earth's axis is on the "line" that divides day and night, so every location spends half its time in the light, and half in the dark.]

(ANGLE ~ 20-25 min) **The Climate scientists** determined that there is clearly a difference in ANGLES at which sunlight hits different locations on the earth. This ANGLE difference is due to the CURVATURE of the SPHERICAL EARTH. We can see this effect in the simple diagram shown here on page 2 where the light rays are hitting the earth from the side. As you can see, the middle of the "Earth" is lit more brightly, and the higher and lower locations (where the earth curves away) are lit more dimly. We can also demonstrate this effect for any spherical object by comparing it with a flat object. We'll use a round ball [show pilates ball] and light from this powerful spotlamp [shine portable spotlamp from far enough to illuminate the whole ball]. Let's turn off the lights so that we can see it more clearly... notice that the illumination is brighter in the middle where the surface is "flat on", and dimmer where the surface is "curving away." [allow students to move around so all can see] Let's compare this illumination on a sphere to illumination on a flat disk... [do this] the disk is lit more uniformly... it has the same "brightness" all over, unlike the earth.

Now we will try to model the view from space, as it relates to ANGLE, and see if we can verify CSI findings about angle for ourselves.
**EARTH and SUN GEOMETRY**  (photo not to scale... distances approximate)

<table>
<thead>
<tr>
<th></th>
<th>Kilometers</th>
<th>Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter of Earth</td>
<td>12,700</td>
<td>7,900</td>
</tr>
<tr>
<td>Diameter of Sun</td>
<td>1,400,000</td>
<td>870,000</td>
</tr>
<tr>
<td>Distance from Sun to Earth</td>
<td>150,000,000</td>
<td>93,000,000</td>
</tr>
</tbody>
</table>

**ANALYSIS:**

- **Earth radius**
  - ~ 4000 miles

- **Rays of sunlight travel 93,000,000 miles to get to the Earth**

**DISTANCE** - light travels approximately the **SAME** distance to each location
  (the difference is extremely **small** compared to the distance from the sun)

**TIME/duration** - each location is on the sunny side of the spinning earth
  for the **SAME** amount of time

**ANGLE** - angle of incoming light at the three different latitudes **VARIES**
  because of the **CURVATURE** of the **SPHERICAL EARTH**.

---END OF CSI REPORT---

**Illuminated Sphere**  **Illuminated Disk**

**FRONT VIEW DEMO:** illumination on a spherical object can vary due to **CURVATURE**
First, on our models of the earth, let's find the travelers' three locations... use the globes at your desks. We're aware of their specific latitudes, or distances above the equator. On page 3, you can see some simplified pictures of the earth that show the latitude at each location. The top picture also shows light shining at the earth in the same direction as sunlight comes toward the ground in Miami.

**DEMONSTRATE:** Put a flat card on “Miami”... & shine a bright light at “Miami” on a large globe (or ball), horizontally from the side, representing the sun, keeping the position for March (when sunlight reaches both poles of the earth)

We can imagine and draw a flat spot and a person standing at any location on the earth to model the "level" ground at that spot. We can also think about the angle that the light makes with the orientation of the person. This angle represents the angle at which sunlight hits the earth at that location. We show a model of some of these “light rays” over on the far right.

So, the second Miami picture (to the right) is a copy of the left diagram, just turned a little bit so that the "ground" in Miami looks horizontal/level (like it does to a person in Miami!).

**Ask students to repeat this mental exercise,** modeling light rays shining at Kalamazoo and Hudson Bay, and a person standing in each place. They may use pencils or markers or strings or fingers or whatever they like, to be able to eventually draw several “light rays” as they hit the ground in Kalamazoo and Hudson Bay.

Look back into your NOTEBOOK PAGES and see if you can find some pictures of light coming toward earth at different angles at the three different locations.(#4, p.3)

Note that the ray diagrams for each location are the same for the view from space as they were for the view from the ground. Great, our two perspectives agree that sunlight reaches the ground at different angles, more or less slanted depending on the latitude.

Let's check on the area covered by light shining on the surface at different angles. [can be demo and/or student test] With a flashlight, shine a beam directly at the equator and gradually move it up, remaining horizontal. See the AREA grow larger. The light on the surface grows dimmer (less intense) until it's just skimming over the top of the globe. When the light is less intense (further North) there is less of a heating effect (the light energy is spread out over more area).

Teacher guides students to complete the SUMMARY of MORE or LESS
**Modeling space-based observations**  Flashlights shining on models of earth (put flat card at location!).

<table>
<thead>
<tr>
<th>MIAMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude of Miami, FL 25°N</td>
</tr>
<tr>
<td>Equator 0°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KALAMAZOO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude of Kalamazoo, MI 42°N</td>
</tr>
<tr>
<td>Equator 0°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HUDSON BAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude of Hudson Bay, Canada 61°N</td>
</tr>
<tr>
<td>Equator 0°</td>
</tr>
</tbody>
</table>

**Fill in the blank with “MORE” OR “LESS”:**
Due to the curvature of Earth, the higher the latitude, the MORE slanted the light on the ground, the MORE area covered by the same amount of light energy, the LESS intensity of light energy on the ground, and the LESS heating effect.
With our "view from space," we now have an even better understanding of **WHY** different locations at different latitudes receive sunlight at different incoming "angles." The **CURVATURE** of the **SPHERICAL EARTH** causes different **ANGLES of incoming light** at different latitudes... different angles are the cause of the difference in heating effects, even with the same amount of overall sunlight striking the earth. [have students fill in blanks on this page - with **ANGLE** & **CURVATURE**]

So our new space perspective and our ground perspective **agree on all counts.** Our Travelers’ Tale was a puzzle that aroused curiosity, and the mystery was solved by careful observations, modeling, science knowledge, math and geometry knowledge, and piecing it all together.

Tomorrow we’ll start uncovering Mystery #2, the Stay-at-home’s Story.

But first... let's see if we can apply what we learned.

("~ 10 min")

**APPLICATION:**

**Just for fun... What if... ?**
1) ... the **travelers** had gone due West instead of South. Would they have encountered a similar difference in temperature between Hudson Bay, Canada and Anchorage, Alaska? (students may explore with globes and group discussions... Teacher may guide and assist as needed)
   (No they probably wouldn’t have... because they are at about the same latitude, same incoming angle of light, same heating effect, which is not much heating!).

2) ... the **travelers** had jumped onto a boat in Miami and continued going South, and kept traveling down past South America and past Cape Horn. Would it just keep getting hotter and hotter? (students may explore with globes and group discussions... Teacher may guide and assist as needed)
   (not after passing the equator .... it would gradually begin to get colder and colder again! As the angle of the incoming light became more and more slanted, just like in the North!)
AGREEMENT ON THE SOLUTION TO MYSTERY NO. 1 -

GROUND VIEW AND SPACE VIEW
AGREE ON THE CAUSE OF
CLIMATE VARIATION WITH LATITUDE...

ANGLE!

ANGLE EFFECT is due to the CURVATURE OF THE SPHERICAL EARTH.

APPLICATION:

WHAT IF... ?

1)... the travelers had gone due West instead of South. Would they have encountered a similar difference in temperature between Hudson Bay, Canada and Anchorage, Alaska?

2)... the travelers had jumped onto a boat in Miami and continued going South, and kept traveling down past South America and past Cape Horn. Would it keep getting hotter and hotter?
# 6 Teacher Supplement

TEMPERATURES VARY WITH TIME OF YEAR

Part I - View From the Ground

Objectives and Resources

**Lesson Objectives:** Learners should be able to:

3. Explain why the intensity of surface illumination depends on angle, and compare cases (by considering area illuminated by a beam).
9. Describe how earth’s temperature varies with time of year (seasons).
10. Compare the apparent (observed) motion of the sun in the sky at different times of year (midsummer and midwinter).
11. Explain why temperatures on earth vary with time of year (seasons). Do this from both a ground-based and space-based viewpoints.
12. Explain that distance from the sun is not a factor in causing earth’s seasons.
13. Show how basic principles of science and math apply in real world situations
16. Represent physical systems and behavior by geometrical diagrams and sketches.
17. Relate a change in one quantity to a change in another.
19. Explain that scientific questions are answered by gathering and analyzing evidence and using scientific knowledge and principles.
21. Think critically and logically to make relationships between evidence and explanations. Distinguish between observations and inferences.
23. Use models to explain and predict phenomena.
25. Develop descriptions, explanations, predictions and models using evidence.

**Lesson Resources:**

Notebooks/pencils/colored pencils
Notebooks, colored pencils, sharpener
Portable spotlight 1
Black, light-blocking fabric
Posters of WINTER & SUMMER, 2 sunsets and 2 sunrises, times, temps
(additional items for interest, TBD)

**Color Coding:**

BLACK: general text (BOLDED for essential points)
BLUE: action notes for teachers
GREEN: student inputs - spoken, written, drawn (students may fill in as they go)
RED: outline topic and approximate timing
Lesson # 6 – [Review ~5 min]
As you recall, light energy can heat a surface. What does the heating effect depend on? [Elicit time, distance, & angle… yet again].

We used this scientific knowledge about light to explain the FIRST MYSTERY of why temperatures vary so much with locations at different latitudes. What was the explanation from both the ground and space based perspectives? What was the major cause of this variation? [ANGLE!]

[Story ~5 min] Now it’s time to use the same knowledge to help explain the SECOND TEMPERATURE MYSTERY, the STAY-AT-HOME’S STORY… in which temperatures vary across the course of a year.

As we did with the first MYSTERY (Traveler’s Tale), we’ll start with the “View from the Ground.” What do people experience and observe in their daily lives at different times of the year?

Picture the scene: this family lives near the city of Chicago, and stays in town the whole year ’round. Here is what they notice as the year goes by.

It’s December. It’s cold and snowy. They can go skiing, ice skating, playing hockey, and building snowmen. Then they can return home for some hot chocolate by the fireplace.

Six months pass by. Seasons change. Now it’s June. It’s really warm. They can go swimming, boating, picnicking, and walking in the park by the lake. Then they can return home for some burgers and cold lemonade on the back patio.

Throughout the year, this family takes photographs and records temperatures. Let’s look at a couple of these…
# 6 - TEMPERATURES VARY WITH TIME OF YEAR

Part I - View From the Ground

**REVIEW**

Light energy can **heat** a surface, and the effect depends on **time, distance & angle**

THE CAUSE FOR TEMPERATURE VARIATION WITH LOCATION IS **ANGLE**

. . . **ON TO THE SECOND TEMPERATURE MYSTERY!!**

**MYSTERY # 2 - Stay-at-home’s Story -**

Temperatures vary with time of year.

**MYSTERY #2 - Part I - VIEW FROM THE GROUND**

**The Stay-at-Home’s Story**

This family **stays at home** near the city of **Chicago** the whole year ’round. Here is what they notice as the year goes by.

It’s **December**. It’s **cold** and snowy. They can go skiing, ice skating, playing hockey, and building snowmen. Then they can return home for some hot chocolate by the fireplace.

Six months pass by. Seasons change. Now it’s **June**. It’s really **warm**. They can go swimming, boating, picnicking, and walking in the park by the lake. Then they can return home for some burgers and cold lemonade on the back patio.

(*Throughout the year, they take photographs and record temperatures)
Clearly, there is a great temperature variation between December and June in Chicago. We can mark the temperature readings like we did the other day, on these thermometers. The height of the column reflects how warm it is... if it's high, it's very warm... lower, less warm. [mark thermometers on transparency]

When we look at the scene over all four seasons of the year it's even more clear that temperature varies throughout the year in this place.

So, the temperature changes as the year goes by. But the reason "WHY" presented a mystery for a very long time. Science (and our amazing Chicago Seasons Investigation team, CSI) has much to tell us about the solution. [Be sure to draw attention to why the CSI name has changed... SEASONS now instead of CLIMATE]

You might not think of it as much of a mystery just because you are so used to it that you take it for granted. But there are some interesting aspects to this story that you might not have thought much about yet.

Given the Stay-at-home's story, the CSI (CHICAGO SEASONS INVESTIGATION) team gathered more clues and collected more evidence, so that they could explain Chicago's large temperature difference between December and June in terms of the science of light that we've been discussing.
**CHICAGO**

**December (winter)**
- cold . . . brrr!

**June (summer)**
- warm . . . whew!

<table>
<thead>
<tr>
<th>December</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>- cold . . . brrr!</td>
<td>- warm . . . whew!</td>
</tr>
</tbody>
</table>

**TIME GOES BY**

*Over four seasons...*

The CSI team – CHICAGO SEASONS INVESTIGATORS – Gathered clues . . . collected evidence . . . explained !!!

**"READY-MADE SCIENCE"**
Temperatures vary with the time of the year because...
[CSI Report ~15-20 min] From their results, the CSI team concluded that the major causes for different temperatures at different times of the year are not only the varying angle of incoming sunlight, but also the duration of daylight upon the location. Distance was still apparently not a cause.

The CSI team visited Chicago at each time of year ... and we will take a careful look at the evidence in their report, and see if their conclusions seem justified.

Within the first column, we find numerical evidence to confirm the temperature variation with time of year, as the homebodies reported. It's always good to have more evidence.

From the CSI team's observations of 10 hours and 15 hours of daylight in each location, we can infer that the time factor may be involved in the observed differences in temperature.

But it seems that we can rule out the distance variable again. The sun appears to be about the same size in the middle of the day in both December and June. Therefore, based on observation of the size of the sun, we can again generally infer that it's about the same distance away from Chicago in winter and summer.

Let's look at the pictures in the second column. These are pictures of a “celestial dome”... which is a model that illustrates where things would appear in the sky from the point of view of a person standing at its exact center. [show them the picture on their page 6 so they can visualize the half-sphere/dome]

Obviously, the sun is much farther away than it looks in this pictorial model... but this model does show the appropriate angle from the perspective of the observer. We see the person viewing the Midday Sun in December and in June ... and its height above the horizon. Notice that in December, the sun is much lower in the sky.

The CSI scientists have used the height of the sun in these pictorial models to help them figure out how to draw the Ray Diagrams that represent (or MODEL) the angle at which the light must have been coming from the sun toward the person on the ground. The lower the sun is in the sky, the more slanted the rays come toward the ground. Remember that the rays are shown as parallel because the sun is very far away. Notice that in December the rays are much more slanted. In June they are almost perpendicular to the ground.

Remember, we learned about the Science of Light that relates the angle of incoming light to the temperature on a surface... [remind them that when a certain amount of light comes in at more of a slant (forms smaller angle with surface), it spreads out over a larger area and is therefore less intense upon the surface... less concentrated. It causes less heating effect. In this case, the longer length in the Ray Diagram for December is an indicator of the light covering a larger area.] So that is why the difference in angle is again a cause for the differences in temperature during different SEASONS.
CONCLUSIONS:
The major causes for **DIFFERENT TEMPERATURES** at different times of the year are the **VARYING ANGLE** of incoming sunlight and the **VARYING DURATION** of daylight upon the location. Distance is not an apparent cause.

EVIDENCE:

**DECEMBER 21**
Temperature - 20° F
Daylight duration - 10 hours
Midday Sun:
- Apparent Size - usual
- Elevation - low

**JUNE 21**
Temperature - 82° F
Daylight duration - 15 hours
Midday Sun:
- Apparent Size - usual
- Elevation - very high

Path of the Sun in the Sky
(“celestial dome” - not to scale)

http://www.eos.slu.edu/People/CEGraves/Eas138/fg02_02.jpg
(SIMULATION Winter/Summer - Chicago ~15 min)

Let's simulate the situation for Chicago in December and in June, and verify for ourselves the conclusions of the CSI team.

We are going to take a look at an imaginary sky again, right here in our classroom. We will stand like a large group of observers on the ground in Chicago ...

... and we'll watch a simulation of the sun's path across the sky in December and then in June.

We don't need chairs this time. We're all in the same place, just at two different times of the year (you have to use your imagination here!).

[Ask the students to group together at the "appropriate" location with respect to the POSTERS, and watch. There are a pair of sunrise/sunset posters for December and a pair for June, that should be set up in advance] (recorded sunrise/sunset times by posters)

Now imagine that you are truly standing outside in December, and the room all around us is the sky. We are going to be facing South.... The sun is about to rise!

[Dim the lights... switch on and shine the bright spotlight beam at the bottom of the wall to the left side... in the far half of the room]

Ah we have a beautiful sunrise dawning again in the east [POSTER] slowly moving across the sky as we gaze up at it. It reaches a maximum midday elevation when it is right in front of each of us, and then it slowly sinks down toward the western horizon, making a beautiful sunset [POSTER] before hiding away on the other side of Earth. Another day gone...

(recorded sunrise/sunset times placed by posters)
Repeat ... This time, as the sun moves, point toward it with your hands as it traces its path across the sky stopping when the sun is directly in front of you (midday position). Ask a couple of students to stand to the west side and observe and sketch the angle of the arms as they point toward the midday sun. These students will be the "evidence sketchers".

Repeat for June, with the sun coming up in the nearest corner, swinging in an arc that remains high (as shown in the Celestial Dome pictures) and narrate as needed. Have a couple other students be sketchers. When done, have the reporters display their sketches on the board, discuss and ask students to draw arms on their pages at suitable angles.

As you recall, the rays from the sun come straight down along your pointing arms.
Everyone draw a few appropriate parallel rays that represent the angle at which the sun came toward you at each time of year [as shown in green].

Hey! Check back a page and see if your drawings look like the CSI Ray Diagrams for each time of year?! (YES, THEY DO)
Let's simulate the situation for Chicago in December and in June, and verify for ourselves the conclusions of the CSI team.

**Modeling ground-based observations**

Large group of observers on the ground in Chicago ...

... a simulation of the sun's path across the sky in December and then in June.

<table>
<thead>
<tr>
<th>December 21</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Diagram" /></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>June 21</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image2.png" alt="Diagram" /></td>
<td></td>
</tr>
</tbody>
</table>

Do our diagrams match up with the CSI Ray Diagrams for each season? **YES**
Now we’ve seen some data and we’ve enacted the scene from the ground… we need to review the connections between the evidence and the CSI claims about the causes for Seasons.

We verified that “time” is a possible reason for the difference in temperatures between Seasons, because there time/duration of daylight upon the ground varied between Seasons (15 hours in summer, and 10 hours in winter).

We also verified that the angle of incoming sunlight is a cause of temperature variation between seasons… because … the lower the sun, the more the slant, the larger the area covered by the same amount of light energy, the less intensity, the colder (the more wintry!)

We verified that distance does not seem to be a cause for seasons, because the sun looks like it’s about the same distance away in winter and summer.

After all this consideration of the evidence, do we agree with the CSI conclusion based on the “view from the ground”?  YES

Does this conclusion make sense with the science of LIGHT we developed earlier?  YES

As far as a "view from the ground" goes, Mystery No. 2 seems to have been solved! 😊

The main suspects are: angle and duration of daylight (time)

Do applications 1 & 2, .... Independent work, but class discussion afterward
SUMMARY

Do we agree with the CSI conclusions based on the “view from the ground”? YES

According to a “view from the ground,”
Mystery # 2, “Why does temperature vary with time of year?”
has been SOLVED!

The main culprits are ___ANGLE and TIME (duration of daylight)___
APPLICATIONS -

1) Starting from the CSI ray diagrams (page 3 of today’s lesson), and given what we learned today about how angle affects temperature variation between seasons, see if you can predict what the ray diagrams should look like for all four seasons in Chicago… (just show some “rays” of sunlight coming down at approximate angles)

   ___________________       _____________       _____________       _____________
   Winter                       Spring                         Summer                     Fall

2) Also referring to page 3 of today’s lesson, see if you can draw “The Path of the Sun in the Sky” for March 21 and September 22… where is the sun at midday? Can you connect this to the ray diagrams above? Can you see a connection to the time/duration of daylight?

Celestial Dome - shows path of the sun in the sky as viewed by a person at the center
TEMPERATURES VARY WITH TIME OF YEAR
Part II – View from Space

Objectives and Resources

Lesson Objectives: Learners should be able to:
9. Describe how earth’s temperature varies with time of year (seasons).
11. Explain why temperatures on earth vary with time of year (seasons). Do this from both a ground-based and space-based viewpoints.
12. Explain that distance from the sun is not a factor in causing earth’s seasons.
13. Show how basic principles of science and math apply in real world situations
14. Use science and geometry to predict the effects on earth if certain factors were different (e.g. if earth’s axis were not tilted or if orbital distance varied significantly).
16. Represent physical systems and behavior by geometrical diagrams and sketches.
18. Use mathematics in aspects of scientific inquiry.
19. Explain that scientific questions are answered by gathering and analyzing evidence and using scientific knowledge and principles.
21. Think critically and logically to make relationships between evidence and explanations. Distinguish between observations and inferences.
23. Use models to explain and predict phenomena.
24. Communicate scientific procedures and explanations.
25. Develop descriptions, explanations, predictions and models using evidence.

Lesson Resources:
Notebooks/pencils/colored pencils
Flashlights (1 per group)
Basketball or Sun ball
Small sun ball (tennis ball?) (1 per group)
Beach ball globes, small globes/balls, small styrofoam balls
Bracelets (1 per student) and hula hoop (1 per class)
Rulers
String (1 radius for each month, 12 total, large model)
Firm card stock (2 per group)
Very small dolls (1 inch or so) (1 per group)
Portable spotlight (1)
Teacher’s Globe

Color Coding:
BLACK: general text (BOLDED for essential points)
BLUE: action notes for teachers
GREEN: student inputs - spoken, written, drawn (students may fill in as they go)
RED: outline topic and approximate timing
Lesson # 7  -  [70-75 min]

[Review~5-10 min] Let's have a brief review ... last week we learned that the heating effect of light energy on a surface varies with time, distance, & angle.

We learned the solution to the first mystery (climate) from two perspectives, from the ground and from space. Yesterday we started exploring our second mystery regarding differences in winter and summer temperatures.

We learned that distance was not an obvious factor... the sun “seemed like” it was the same size in the sky in December as it was in June.

We looked at the observed behavior of the sun from the ground perspective, and saw that in the winter it was much lower in the sky, and the daylight hours were shorter. From this, we concluded that the ANGLE and TIME/DURATION of sunlight were causes of temperature variation over the course of a year (in Chicago).

But scientists (and our CHICAGO SEASONS INVESTIGATORS - CSI) don’t stop here: they also want to know WHY the sun has such “strange” behavior, sometimes low, sometimes high, different paths...

(REPORT FROM SPACE ~40 min)
To explain WHY the sun changes its apparent height and path across the sky during the course of the year, the CSI team needed another perspective... a “big picture” view of the earth and sun system as viewed from space.

So, they collected and analyzed information from Space Science Experts, and found evidence that supported both ANGLE and TIME but not distance as likely factors in temperature variation with time of year. Let’s see how they came to the conclusions in their REPORT...

First, these big pictures of Earth show Earth’s TILT with respect to incoming sunlight in June and in December, six months apart. See how Chicago’s [imaginary] latitude line (shown in blue) is lit by incoming sunlight at each time of year. [point out the latitude line, clarifying that over each day, Chicago rides around the earth on that line, and that the bright side is the daytime, the dark side is the night.]

From the pictures, you can tell that the sun must be on the sunny side... 😊
# 7 - TEMPERATURES VARY WITH TIME OF YEAR Part II - View From Space

**REVIEW**

Heating effect of light energy varies with time, distance, & angle.

For MYSTERY #2, the Stay-at-Home's Story, the "VIEW FROM THE GROUND" indicated that **ANGLE and TIME** are main suspects for causing temperature variation with time of year (seasons). **distance** is not an apparent factor for temperature variation with season.

**MYSTERY #2 - Part II - VIEW FROM SPACE**

---CSI REPORT FROM A REMOTE LOCATION---

Chicago Seasons Investigation

**CONCLUSIONS:** Scientific "view from space" supports **ANGLE**, and **TIME**, but **not distance** as apparent causes for Earth's temperature variations throughout the year.

**FACTS & FIGURES:** Sunlight upon the spinning EARTH (constant 23.5° TILT shown, which causes **ANGLE** and **TIME** effect)

Latitude of Chicago shown in blue (42° N of equator)

- June 22
- December 22
On this next page, we can see evidence that in summer and winter the earth is at opposite sides of its orbit around the sun. It takes a full year (12 months) for the earth to go all the way around the sun, and some of its locations during the year are pictured in the CSI’s EARTH and SUN GEOMETRY TABLE.

An important point to notice from these pictures is that the TILT of the earth is always in the same direction in space... the earth’s rotation axis [the imaginary line it SPINS around] points the same way in space no matter where the earth is in its path around the sun. Let me demonstrate what I mean by that... [ask for student volunteer to be the SUN and stand holding a basketball...]

Now I am holding the Earth and it is December, everybody please point with your arms in the same direction as the earth’s axis, as though you are the earth [starting with correct tilt for December ... teacher/"Earth" walks around the sun holding a globe rigidly in front of them, with pencil held as an extension of axis (no rotation, base flat in orbit plane), KEEPING face toward the SAME WALL the entire time ... AS YOU GO AROUND, repeatedly ask them to: Point again in the same direction as the axis... Notice that all the time the AXIS (and you!) are pointing the “SAME WAY in space” not the same way toward the sun. In other words, it does NOT do this [Starting from December, you walk around the sun holding the large globe rigidly in front of you (no rotation, base flat in orbit plane)... keeping your face toward the SUN, earth’s axis tipped away from sun]. Would any of you students like to demonstrate one more time how the TILTED Earth DOES orbit the sun? [assist if needed, for correct last look].

Well now that we’ve clarified the TILT issue, let’s look at the DISTANCE issue. In our Earth and Sun Geometry Table, we can also see some numerical data about how far away the sun is from the earth at different times of the year. The earth’s orbit is not a perfect circle and at times the earth is slightly closer to the sun and at times slightly farther away. But these differences are very very small.

The earth’s average distance from the sun is defined as 1 astronomical unit (about 94 million miles). This unit is more convenient to use than miles or kilometers when studying objects in space that are very very far apart.

The small variation from the average distance can be seen in the TABLE. Notice that the earth is actually slightly farther away from the sun in June and July than it is in December and January. You can verify this for yourselves by measuring the distance from the sun to the earth at these times in a fairly accurate drawing of the shape of earth’s orbit around the sun... (next page)...

T Light Direct # 7 – page...
### EARTH and SUN GEOMETRY TABLE

(picture not to scale... distances approximate)

<table>
<thead>
<tr>
<th>Date</th>
<th>Distance from Earth to Sun in Astronomical Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 21</td>
<td>1.016</td>
</tr>
<tr>
<td>June 22</td>
<td>1.004</td>
</tr>
<tr>
<td>Sept. 23</td>
<td></td>
</tr>
<tr>
<td>Dec 22</td>
<td>0.984</td>
</tr>
<tr>
<td>March 21</td>
<td>0.996</td>
</tr>
</tbody>
</table>

(AU ~ 150,000,000 kilometers, ~ 94,000,000 miles)
Here we can see how the earth moves around the sun in a counterclockwise direction. Measure and compare the distance between earth and sun in June and December. What did you find? [kids share ideas]

Do your measurements verify that the earth’s orbit is nearly circular? [discuss] Interestingly, here again you may notice that the Earth is actually a bit closer to the sun in December…. but only by a little tiny bit, [about a 3% difference].

The earth’s orbit is nearly circular… like this hula hoop. But pictures of it might not always look like a circle. Let’s become familiar with some other views of the orbit.
Measure and compare the distance between earth and sun in June and December.

Findings:
After analyzing the data, the CSI team sketched models to clarify the **geometry of the earth and sun**, and how it relates to temperature variations on earth. At the top of your page you can see three different ways of looking at the earth's orbit around the sun. The “top” view on the left side is similar to our previous diagram.

If you looked in at that circular orbit from the side, it would look flat like it does in the picture on the right. The oval middle picture is just a view halfway between the other two. It looks like a round plate does when you are sitting at the table in front of it. [teacher passes out bracelets to help students visualize these perspectives, and uses the hula hoop to demonstrate each view for them]

As we saw in the TABLE of distances, even though the orbit is almost a circle, the earth is actually **slightly** farther away from the sun during the summer (June & July). So there is even more evidence that the **DISTANCE** from the sun does not explain why we have seasons on the earth.

As far as the **TIME/DURATION** of daylight, the CSI team found it does relate to climate differences. As they saw the Earth rotate/spin on its tilted axis through a full day, like this [show rotating globe, set on a tilted axis... do with darkened room, bright light, reflective tape marking Chicago... discuss the “Chicago daylight” vs “Chicago in the dark”] Chicago is visibly on the daylight side of the earth for a longer time in June... and a much shorter time in December. You can see this well in the color picture on page 1 of today's lesson... when you compare the lengths of the blue “Chicago” line that are in the dark and in the light at each time of year. The reason the **TIME** varies over the course of a year is the TILT of the earth. If the earth's axis was not tilted the duration of day and night would be just the same all year.

Now we will think about how the **view from space** at two different times of the year helps us relate **ANGLE** to temperature variation. From the bottom CSI diagram on page 4, we can see that because of the **TILT** of the earth, sunlight reaches the ground in Chicago at different **ANGLES** in June and December. In June, Chicago “tilts toward sun” - light is more straight-on. In December, Chicago “tilts away from sun”- light is very slanted in December. **To check this for yourself**, place two globes at your table to represent the earth in June and December, with the sun in between. Keeping in mind where the sunlight is coming from, you can model a straight-line "light ray" with a pencil to help you “see” how the light hits the ground at each time of year. [to reflect this on the diagram, you can add/extend some rays all the way over to a tangent line (at Chicago).... Like Lesson #5... Help students connect observations of different angles of incoming light to the ground with the temperature variations as studied in our basic light kit – more straight-on, more illumination, more intensity/heating]
EARTH'S ORBIT – Three Views

DISTANCE – Earth’s orbit around the sun is almost circular... so sunlight travels approximately the SAME distance to earth throughout the year (about 1 astronomical unit). The earth is actually farthest from the sun in June/July and closest to the sun in December/January.

TIME/duration – Length of daylight is longer for the Northern or Southern hemisphere depending on which half is TILTED toward the sun.

ANGLE – angle of incoming light VARIES over the seasons because of the TILT of the earth.

---END OF CSI REPORT---
So we have seen that both the GROUND view and the SPACE view agree that incoming sunlight changes ANGLE over the course of a year, and that days are shorter in winter, and longer in summer. The AXIS TILT of Earth explains all of these facts. So TILT is the reason for the seasons, and we could not “see” this important fact until we took a view from SPACE.

Now for some applications of all this knowledge we have gained... and a reminder of the factors that cause both seasons and climate ...

**LARGE MODEL CONSTRUCTION ~10 min** Next we are going to build a model for ourselves... a rather large one. We’ll represent the earth going around the sun... over 12 months of the year... using these EARTH balls/globes and a basketball SUN. You will need to apply information and understanding you’ve gained in today’s lesson to figure out how to position the earth at each month, with respect to the sun. I’ll pass out “month” cards that will randomly assign a couple of people to each month. [may be good to let each month be handled by two people at the same table]

We will place the “SUN” at the center of the room, and then we’ll assign a particular location in the room to place “Earth” in December, so that everyone can figure out where they need to put their own month. Every group will need to orient the earth at the proper tilt with respect to the sun for their month, and show Chicago AT MIDDAY (noon).

You’ve got all the information that you need to place Earth correctly in its orbital path, but please ask if you have any further questions [guide students as needed, especially toward using the information in this lesson...]

**Including the fairly CONSTANT DISTANCE of earth from sun, as represented by 12 strings (one per month), each “1 AU” long (Astronomical Unit)**

**Including the COUNTERCLOCKWISE DIRECTION of orbit... in fact, a helpful analogy might be a clock, for locating the months by the hours on a clock, with December “12 noon,” January 11 am, February 10 am, and so on.**

** Including that MIDDAY means that the longitudinal line of Chicago is facing the sun.**

** Including the fact that the TILT is always oriented the same way in space. Varies only as “seen” from sun**

[Once all the globes are properly oriented, try using the spotlight (or have a student try), to shine from the center of dark room, check the class model... for accuracy and for how many things it illustrates about how sunlight warms the same location on Earth at different times of the year...SEASONS] [STUDENTS CAN ROTATE AROUND SO THAT THEY CAN ALL SEE WINTER AND SUMMER UP CLOSE]

This model represents what we’ve learned about how sunlight relates to SEASONS. Because of the permanent TILT of Earth’s axis, in December Chicago (in the Northern Hemisphere) is “leaning away from” the sun with rays more slanted and less heating effect. This “leaning” changes gradually as the year passes, so that in June the Northern Hemisphere is “leaning toward” the sun more, rays more straight-on, more heating effect.
AGREEMENT ON THE SOLUTION TO MYSTERY #2 -

GROUND VIEW AND SPACE VIEW
AGREE ON CAUSES OF
SEASONAL TEMPERATURE VARIATIONS...

____________________ ANGLE & TIME____________________

These causes are due to the ________TILT________ of the Earth.

A TWELVE MONTH PATH AROUND THE SUN
(cooperative model construction – not to scale!)
(APPLICATIONS - seasons and climate ~15 min)
(consideration of “variables”)

Discuss each thoroughly; students refer to lesson info and globes, and should be encouraged to participate in discussion whether or not they write “explanations”

Guide toward…

1) a) YES, seasons opposite of the Northern Hemisphere
   
   b) YES, earth is still curved

2) a) NO, because without TILT the ANGLE and DURATION of sunlight do not vary over the course of a year at the same location.

   …ANGLE and TIME differences both cause differences in heating effect

   b) YES, because the earth would still have its CURVATURE… and thus, different ANGLES of incoming light at different latitudes
APPLICATIONS:
Answer with an explanation of your reasoning...

1) What if you lived in the **southern hemisphere** of the Earth?

   perspective view...
   (actual tilt)

   a) ... would you still have different seasons? If so, how would they compare to the seasons in the **northern hemisphere**?

   b) ... would there still be different climates at different latitudes?

2) What if the earth's axis was straight up and down (not tilted) with a perspective view as shown here:

   perspective view...
   (no tilt)

   a) ... would there still be different seasons at different times of year?

   b) ... would there still be different climates at different latitudes?