Through Thick and Thin

Purpose

In this Thread, we will discover how a given amount of light changes in intensity when the area it shines on changes.We will also make a final observation about the change in light and heat that happens when we tilt towards or away from the Sun. This explains why things seem less warm during the winter months, when the section of Earth we live on is tilting away from the Sun. The National Science Education Standards call for our students to learn how the seasons happen. As well as thinking about the changes on the Earth, this Thread adds another piece to the story which is often ignored: position and the way light and heat work. Vocabulary words we can introduce here to help us talk about our experiences are area, tilt, and intensity.

Teacher Background

Light travels very directly, in straight lines. And because light behaves both like a very direct wave and like traveling particles means that as light hits something, it transfers some of its energy to the surface of that thing. In this Thread we will discover that the amount of light that hits a certain spot can actually be reduced. This seems like it contradicts what we just said about light. However, the key is that if the surface is slanted or tilted at all, the amount of light that was reaching it still reaches it, but it is spread out over a wider area now instead of falling directly in a more condensed region.

> You will need: sets of the following for half of the class: clipboards, construction paper, thermometers, bricks or books for propping things up, pencil, graph paper, flashlights.
>
> Materials gathering time and set-up should not take very long, providing there are clipboards handy.

The conservation of energy principles at work here can be compared to the act of making a peanut butter and jelly sandwich. Since we use that analogy in the Threads to think more about what we are seeing, the analogy has been reproduced here in the Teacher Background so that you don't have to search for it in the text of the Thread itself.

Think about making peanut butter and jelly sandwiches. Imagine you are only allowed to have a spoonful of each ingredient, but you have a choice between both large or small pieces of bread to spread the ingredients over. If you had a choice between spreading those spoonful amounts over huge pieces of bread or smaller ones, which sandwich do you think might taste better? Why? Think about the thickness of the sandwich in relation to the bread size. Then we can bring the meaning around full circle.

If there is only a spoonful of light, on which board would the light spread "thicker": the one where the light gets spread over a small region or where it is spread over a larger region? And then, on which board is the region getting "thicker" heat and light? Light which is spread out is not as warm or as bright as light packed together. Light is made up of little bits of energy. If a light source is only so powerful, it can only ever create so many particles of light at one time—a spoonful, perhaps? In the winter for us, our hemisphere of the Earth is tilted back at an angle from the Sun, and so the sunlight is spread out along that angle. Spread-out sunlight means cooler temperatures.

One thing to remember about the planet Earth is that our atmosphere works like a big blanket to keep heat on the surface longer. This is why the longest day of the year, the summer solstice, is rarely if ever the hottest day of the year. It takes time for the surface of the Earth to heat up or cool down, with the atmosphere surrounding it. Therefore, it takes time for the heat to build up on the surface to give us the hottest day of the year. Conversely, the auumn happens slowly as the heat from the high Sun's path during summer is still dissipating.

In general, complete heat transfer is never very speedy. It takes time for a cup of coffee to cool down or for a pot of water to boil on a fire. Imagine if you were to insulate those items by using a buffer zone between the two different temperatures. Depending on the quality of the insulator, the coffee might never cool or the pot might never boil. The atmosphere is in many ways an insulator, keeping most of the frigid temperatures of space from reaching the surface of the Earth and keeping the warmth of the planet's surface from completely leaving it. Thus, we have a small range of temperatures on the planet compared to what they might be if there were no atmosphere. For example, the Moon, which is essentially orbiting the Sun at the same average distance as the Earth, has day and night surface temperatures of 266°F to -274°F, respectively. The range is so incredible because the Moon has no atmosphere, really, to blanket its surface.

So, thinking about the change in tilt as the only factor in the change in seasonal temperatures is not all of the story. We need to think about the fact that the process is not abrupt for two reasons: one, the orbit of the Earth is slow compared to the change in orientation of the axes with the direction of the Sun; and the atmosphere buffers the transfer of heat to and from the surface, hence slowing it down.

Kindergarten through Second Grade

Developmental Issues

For this age group, this Thread focuses on the concept that heat from the Sun changes if the surface it hits is tilted. If you use the peanut butter analogy, keep in mind that you are asking children to use one instance to reason about another, and they may find the mapping between the two instances to be difficult. You'll need to be really clear that the analogy is only about how "thick" the light is and not anything else. Kids may make other unintended connections. Use the flashlight exercise as the main path to the understanding. We won't build elaborate temperature devices with this group, as they won't be able to manage the delicate cutting required, nor will they understand what the purpose of the device is!

Inquiry Introduction

How does light hit stuff? How did you make a shadow? How do we make shadows longer or shorter? Can we make light longer or shorter? Think about making peanut butter and jelly sandwiches. Imagine you are only allowed to have a spoonful of each ingredient, but you have a choice between either large or small pieces of bread to spread the ingredients over. If you had a choice between spreading those spoonful amounts over huge pieces of bread or smaller ones, which sandwich would you think might taste better? Why? Think about the thickness of the peanut butter and jelly in relation to the bread size. If you could spread a spoonful of light on a bigger or smaller area, which would be warmer?

Inquiry Investigation

With the flashlights, shapes, and the paper/clipboard setups, let students play with shadows. Then remove the shapes. Now, there are no Blockers, and it will be interesting what students can discover about how light hits a surface.

How can you make the beam of light on that paper look different? Make it longer or shorter, brighter or dimmer. What other things can you find out about light? Hopefully, they will be moving the flashlight around a lot. If no one seems to be moving the paper, suggest they try to do so. What happens then? Different amounts of the paper get covered with light when the flashlight or paper is tilted. This is like different-sized slices of bread, right? Outline the regions of light from the beams on the paper.

Dim the lights a bit so that they will be able to see subtle differences in the light. Ask them how they can make the light seem brighter on the paper. What did they have to do? If they moved the flashlight closer to the paper, ask them if there is a way to change the brightness without changing the distance from the flashlight to the paper. Tilt the flashlight or tilt the paper towards each other. Is this like having a sandwich with more peanut butter and jelly? How? Which way can make the light "thicker"? Is the light also brighter when it is thicker? Is the light warmer when it is thicker?

If the Earth is a big object for sunlight to hit, what happens when part of it tilts towards the Sun? Grab a globe and overhead projector to demonstrate this. The light will seem more intense. How is this like the paper tilting? So the light is thicker and brighter when the globe is tilted towards the light. What about the temperature? Would it be warmer or cooler in that case? What season would that be? What about if the Earth were tilted away?

So, why do leaves die in the Winter? What is it that leaves need that they are not getting enough of? Why does it get so cold in the Winter? Why do birds fly south? How have we learned these answers? Just by observing the world around us and using the tools of Scientific Inquiry.

> "There is no prescribed route to follow to arrive at a new idea. You have to make the intuitive leap. But the difference is that once you've made that intuitive leap you have to justify it by filling in the intermediate steps. It often happens that I have an idea, but then I try to fill in the intermediate steps and find they don't work, so I have to give it up."
>
> —Stephen Hawking

> "One can't believe impossible things."
> "I daresay you haven't had much practice," said the Queen. "When I was your age, I always did it for half-an-hour a day. Why, sometimes I've believed as many as six impossible things before breakfast."
>
> —Lewis Carroll, *Alice in Wonderland*

Second Grade through Fourth Grade

Developmental Issues

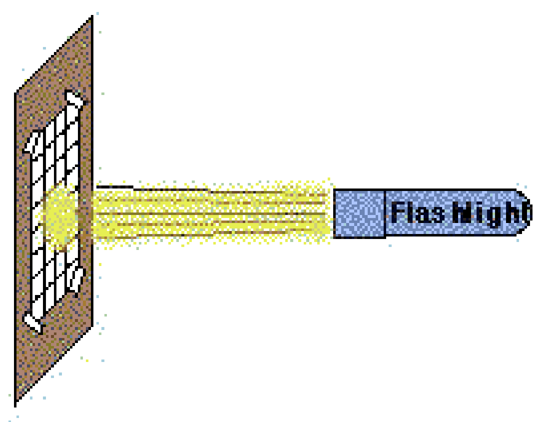
For this age group, the Thread focuses on using some math and building some simpler devices for the classroom. By this age, students are able to count blocks and understand simple concepts about area. So, we'll encourage this. We won't go outside with the clipboard apparatus as we will with the upper grades, we instead will manipulate the ideas in the classroom.

Inquiry Introduction

Is there a way we could really prove that the Earth's tilt makes part of the planet warmer or colder? What does this really mean, then, about light when it hits a tilted surface? Can we make tilted surfaces? Do we have light sources? Let's go for it.

Inquiry Investigation

Hand them flashlights and thermometers. On construction paper, draw a grid like graphing paper. Call it graph paper. Tape the graph paper to a clipboard with masking tape and hand it out to the students. See what they can do with these supplies to understand more about tilt and light.



If they are unsure about where to start, try shining a flashlight straight down on the graph paper board. Then, ask a student to prop up the board so that it is at an angle. What they will notice about this is enough to get them started, because the number of squares they will now see illuminated by the flashlight beam will be very different. How many squares does the flashlight beam cover when the flashlight is shining straight down on the paper? How warm does it feel? What about when the paper is tilted? What is the difference? Can we detect any difference? Should there be a difference? How could we make a record by drawing the difference? Think about graphing or circling the beam where it hits the paper.

Is the flashlight heating the paper up more when it is shining dead on or when it is hitting the paper at an angle? Turn the room lights down lower and ask them to repeat the investigation. Suggest maybe that one group just hold the flashlight above their graph paper and the other tilt their paper. What do you notice about the difference in the two, besides the number of squares the tilted paper has covered? Hopefully, someone will exclaim that the tilted paper is not as brightly lit. This is the key: ask them again then if they think the flat paper is getting warmer than the tilted one.

How much light and heat are coming out of the flashlight? Is the same amount always coming out? If there is only, say, a spoonful of light, on which board is the light "thicker": the one where the light gets spread over a small region or the one where it is spread over a larger region? On which board is the region getting thicker heat and light? Does everyone believe that we have just figured out what is happening? That light spread out is not as warm or bright as light packed together? Light is made up of little bits of energy. If a light source is only so powerful, it can only ever create so many particles of light at one time -- a spoonful, perhaps?

Then ask students if there is any difference between tilting the board and tilting the flashlight. What if we were using a larger, hotter light source, like a halogen lamp, or a star? Wouldn't the heat carried also be less intense when the board is tilted at larger angles? So, when the Sun is lower in the sky, it is like a tilted light source. Or in other words, on parts of the Earth tilted away from the Sun, the Sun's light is not as intense as on regions directly facing the Sun.

What other factors might affect how much heat there was at the surface of the Earth? How can you make sure you are warm even if it is cold outside? How does planet Earth keep us from freezing at night when we are turned away from the Sun? (Consider doing the coat activity as described in **The Keys to Inquiry**.)

So, why do leaves die in the Winter? What is it that leaves need that they are not getting enough of? Why does it get so cold in the Winter? Why do birds fly south? How have we learned these answers? Just by observing the world around us and using the tools of Scientific Inquiry.

> "There's no limit to how complicated things can get, on account of one thing always leading to another."
>
> —E. B. White

> "There are children playing in the street who could solve some of my top problems in physics, because they have modes of sensory perception that I lost long ago."
>
> —J. Robert Oppenheimer

Fourth Grade through Sixth Grade

Developmental Issues

At this age level, students are ready to really grasp this concept and build on it. By encouraging their math skills, ability to abstract, and by getting them to make connections, we hope to bring together the big picture for them.

Inquiry Introduction

How is it that longer shadows mean colder temperature? And why, when the Sun appears to be higher in the sky, does that mean it is warmer down below? How does light travel? In straight lines. Can you tell when the light is on if you have on a good blindfold? How? You get really close to the light and you can feel it. So, there's some kind of stuff to light.

How might we really be able to test the theory that tilting a surface changes the amount of heat it receives? What do we think about light hitting something dead on and light hitting something at an angle? What might be warmer or cooler? With flashlights at the desk, can they tell that a tilted light is not as bright? Can we tell which is warmer or cooler? No, it is not possible, really, since flashlights are usually not very bright. But building the tilt gadgets will. Gather the sets described in the Materials box and head out into the Sun.

Inquiry Investigation

Outside in the sun, bring a few boards with graph paper taped to them. Locate the Sun in the sky. Ask students how to tilt one board so that light from the Sun hits it dead on straight. How could the other board be tilted at an angle to the Sun? Try students' suggestions. Allow extreme angles to be used as well as others.

What do the students notice about how many squares are covered on both boards? They may seem confused by this, because the boards both seem lit. What does this mean about where the Sun is? Lead them to thinking about how big the flashlights were, how close they were to the paper and then about the scale of the Earth and Sun. When they exclaim that the Sun must be far away, ask them then how the Sun can make the planet so bright. They will then figure out that the

Sun is a very bright light source. It is good for the students to ponder about this weird light source we call the Sun. Nothing else in the whole solar system is anything like it.

The graph paper boards are getting warm by now. Ask the students to try and tell which one is warmer. They will have difficulty. How then could we get a more sensitive temperature reading from the boards? Thermometers, of course! But how could you put a thermometer inside the graph paper to measure its temperature? They will ponder this a while. How do you take your own temperatures? In your mouths? Could you make a little mouth on the graph paper somehow? The best advice is a tiny slit cut into the paper so a thermometer can slide in between the paper and the board. What supplies do we need to do this? Bring everyone back inside to gather these.

Is it important to make sure the thermometers are all reading the same temperature right now? When we walk outside, what will happen to the thermometers? Ask them what they do when they are taking their own temperatures. They will probably say they shake the thermometer. Ask them why they do this. They will likely say that they want to make sure the stuff in the thermometer isn't too high up. Could we arrange something which would allow the thermometers to be ready to use, or which would make sure the stuff in the thermometers is not too high when we start? Let's find a way of keeping the thermometers relatively cool even before we begin the investigation.

When we reach the boards, carefully slide the thermometers into the little mouths and record the temperature. If they are not the same temperature initially, ask the students if this is a problem. Do we see anywhere in the area where we could put the boards and thermometers so that we could reach the same temperature? The shade is a good place.

How soon do we think we should see a change in the temperatures due to the tilt? Some students will say hours, thinking of the shadow sticks, others might say seconds. Why? Have everyone take temperature measurements during their guessed amount of time, keeping a very careful record. Beware the effects of clouds and wind, as well as the shadows of over-anxious students! Those who are watching roughly every few minutes will notice a change immediately. Those who were thinking on scales of hours will relinquish this when they see the others' results. Continue making temperature measurements for as long as it takes until the thermometer readings are no longer climbing.

Which paper was heated more quickly? Which got warmest in the end? Encourage them to graph their results carefully, as we've done all year, and describe the differences and patterns they see. Can we calculate in terms of fractions or averages how much hotter the dead-on paper got compared to the tilted ones? For those who used extreme angles, how did they fare up against the dead-on Sun ones and the less extreme angles?

Do we all believe that the Sun is just one big faraway light source? What is going to happen to the temperature of the Earth when summer comes?

When is the coldest day? Usually sometime in January or February. Why is it not on the shortest day of the year, the winter solstice, when the height of the path of the Sun is at its lowest in the sky? Why isn't it the warmest day of the year on the summer solstice? Of course, it takes some time for the Earth to warm up or cool down. The oceans make a big contribution to delaying the heating or cooling of the Earth. In the summer, it is often cooler at the sea coast, and winters along the coast are milder than further inland.

How does a cup of coffee know when to stop cooling down and reach room temperature? How does a Thermos work? (Possibly doing the activity described in The Keys of Inquiry regarding coats might be a good connection to the topic at hand.) How cold does it get on the Earth? Could the Earth's surface get as cold as empty space? Why or why not? Hopefully, they will begin to think about the atmosphere. If not, ask if the Moon's surface could get as cold as empty space. What are some differences between the Earth and the Moon?

Many factors combine to make life on the Earth habitable for all of the species which live here. Even though seasons change, the temperatures are still within a range we can handle, and life has adapted to this planet.

So, why do leaves die in the Winter? What is it that leaves need that they are not getting enough of? Why does it get so cold in the Winter? Why do birds fly south? How have we learned these answers? Just by observing the world around us and using the tools of Scientific Inquiry.

> "When one tugs at a single thing in nature, he finds it attached to the rest of the world."
>
> —John Muir

> "Great discoveries and improvements invariably involve the cooperation of many minds."
>
> —Alexander Graham Bell

To Learn More about Space Science: *Teacher References*

Books and Magazines

Cosmos by Carl Sagan
This book is a personal exploration of the Universe from atoms to supernovae.

Pale Blue Dot by Carl Sagan
This book explores the significance of Planet Earth.

A Demon-Haunted World: Science as a Candle in the Dark by Carl Sagan
This book explores the differences between real science and pseudo-science.

Cambridge Atlas of Astronomy
This is a huge book with photos and drawings of everything in astronomy.

Sky & Telescope Magazine
Astronomy Magazine
These magazines discuss recent astronomy news and seasonal sky viewing.

Websites

http://spacelink.nasa.gov/Spacelink.Hot.Topics/ — Spacelink Hot Topics
This is a site highlighting what's new and hot in space science right now.

http://www.jpl.nasa.gov/galileo/ — Spacecraft Galileo Homepage at JPL
Galileo is in orbit around Jupiter and the Galilean moons taking data. What's it doing right now?

http://oposite.stsci.edu/pubinfo/latest.html — Latest HST Pictures
This site shows the new photos from the Hubble Space Telescope with lots of great information.

http://www.newscientist.com/ — New Scientist Planet Science Page
This is a British magazine which posts some of its best news articles up on the web.

http://seds.lpl.arizona.edu/ — Students for the Exploration and Development of Space
This site hosts the best planetary, galaxy, and nebula information on the Web.

http://www.astro.wisc.edu/~dolan/constellations/ — Stars and Constellations
This site tells you everything you ever wanted to know about the wonderful night sky from folklore to astrophysics.

http://www.nasa.gov/gallery/photo/index.html — NASA's Photo Archive
One-click stop to every NASA photo you have ever seen or not seen from each NASA mission.