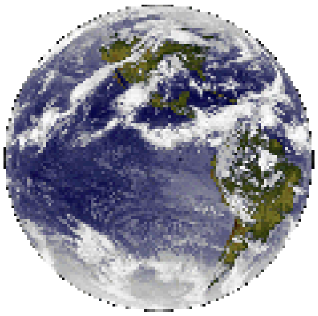


Observing the World Around Us

An Introduction for Teachers and Parents

Our everyday experience of the world around us is an invitation to question and explore and wonder:

During the day, we see a bright sphere called the Sun move across the sky. Its path is fairly regular from day to day, but changes gradually during the 365-day seasonal cycle. Why doesn't the Sun always rise in the same place each day? Where does it go at night? How does its light cast shadows on our world?

We experience the alternation of daylight (day) and darkness (night). Clocks show us that the total time needed to complete one day and one night always is 24 hours, but the proportion of daylight and darkness varies for different 24-hour periods. Also, we can see that the Earth never is completely light or dark at one time. How can it be 12 PM in Boston, 5 PM in London, and 9 AM in San Francisco at the same time? Who has the right time?

Much of the Earth's population experiences a repeating pattern of temperature and weather changes over a 365-day period. Weather in the most populated areas goes from generally cool days (spring) to hot days (summer) to cool again (fall) and then to cold (winter) and back to cool. These seasonal changes affect animal and plant life dramatically. Seasons have different lengths and varying character at different locations on the Earth. How can we have winter in the USA and summer in Australia at the same time, if they both turn toward the Sun once a day?

People have wondered about these and other aspects of our ordinary experience, observing and pondering and guessing about the world we live in. They have constructed "models" to explain the phenomena around us and have refined and changed and discarded these explanations based on further observations and reflections. Much of our current understanding is built upon the inspiration of observers and inquirers starting before Plato (427-347 BC); we owe much to the inspired work of Nicolas Copernicus (1473-1543), Johannes Kepler (1571-1630), and Sir Isaac Newton (1642-1727).

Today we know that the Earth is a sphere that turns on its axis once every 24 hours. The Earth revolves around the Sun, a very large and very hot sphere of gas situated millions of miles away from us. One such revolution takes approximately 365 days. The Earth is tilted on its axis of rotation with respect to the Sun, and this tilt, coupled with the Earth's movement around the Sun, causes the alternation of our seasons. The Moon, in turn, is a smaller solid sphere that revolves around the Earth about every 28 days. It reflects the light of the Sun and shows us its "phases", depending upon the relative position of the Sun, Earth, and Moon.

Although these and other modern scientific explanations can become complicated and even can run counter to our intuition, they really are rooted in the everyday experience of people who wondered about the world around them. This is the essence of science: to be explorers of our own world, to engage ourselves in the Spirit of Inquiry by observing what is around us, asking questions and looking for answers that are consistent with our experience. And although we cannot hope to reconstruct all scientific understanding from first principles, each one of us can be a scientist with regard to our own experience. We can observe the world and wonder about it and see how our observations and deductions mesh with scientific knowledge.

As a point of focus, everyone "knows" that the seasons are "caused" by a tilted Earth revolving around the Sun. But what does this really mean? How can we know that the Earth is tilted? How can we know it revolves around the Sun? And what do the Earth's revolution and tilt really have to do with seasons, anyway? Can we find something in our experience that lends credence to these notions, so that we can deeply understand the facts and not just believe them because we are *told* that they are so?

An Inquiry-Based Classroom

In our Everyday Classroom Tools project, we are seeking to immerse elementary school students in the Spirit of Inquiry, to help them begin to observe and learn from their experience. Our project is rooted in a connected, progressive set of observations and questions which we can use to explore the world around us. We look for answers that are consistent with our experience and with the accumulated knowledge of humankind. At all times we try to keep ourselves rooted in our own observations. We strive to maintain a connection between what we are exploring now, what we have learned in the past, and what we hope to understand in the future. What the Everyday Classroom Tools project wishes to stress is that before there were encyclopedias, there were authors, and before there were scientific facts, there were curious people trying to explain the world around them.

There are more questions we could ask ourselves about the world around us than we present here, because for every observation, there can be many more questions we find and want answered. Hopefully, those questions will be ones which appear in our classrooms from eager and inquisitive students. The first question we asked ourselves when we embarked on this project was "Where do we start to build a curriculum based on these principles?"

Our efforts to date have taken the form of the **Threads of Inquiry**, a series of free-flowing dialogues about inquiry-inspiring investigations that maintain a solid connection with our experiences and with one another. The Threads are meant to be a jumping-off point for teachers, suggesting an approach to the Spirit of Inquiry without dictating too much of the content. They are backed by more formal on-line activities, and they also operate in accordance with contemporary concepts in science education for elementary students (such as the National Science Education Standards).

Accompanying this curriculum is a comprehensive look at inquiry as a method of learning, a companion document addressing the benefits and strategies for educators bringing inquiry into their classrooms. **The Keys to Inquiry** is a useful resource for anyone interested in research on and methods of inquiry-based learning. It is written to be used with the Threads of Inquiry.

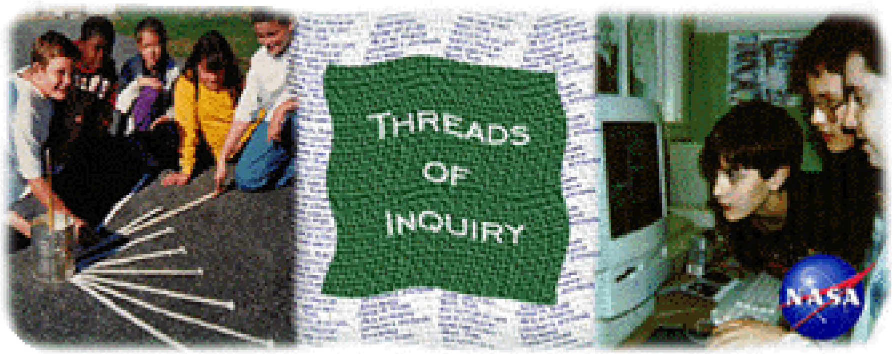
The major theme explored in this curriculum is the pattern of change on planet Earth as it relates to the Sun. So many different subjects can be usefully mapped to this set of investigations of the world around us that it gives educators an opportunity to build upon an inquiry framework with their own related and connected ideas from different disciplines.

Here is a look at each of the different investigations and their main aims with regard to skills and science learned:

Main Skills and Topics Covered by this Curriculum

Name of Thread	Skills and Science Learned
To Seek or Not to Seek?	**Skills**: Observing, collecting, question asking, examination of data, recording of data, changes, patterns, science as a tool. **Topics**: Life cycles.
Hello, Sun!	**New Skills**: Measuring, modeling, predicting, theory building. Using our body as a measuring tool. **Topics**: Sun's path in the sky, Sun's height in the sky, Sun-Earth motions, length of day, degrees on the sky.
You Light up My Life	**New Skills**: Manipulating objects and tools, experimenting with postulates. **Topics**: Nature of light and how shadows are made.
Me and My Shadow	**New Skills**: Thinking about information in different ways, believing a theory by testing it. **Topics**: Nature of light and shadow geometry.

Guess My Shape	**New Skills**: Thinking in more dimensions, bringing our experiences from outside back into the classroom, educated guesses. **Topics**: Nature of three dimensional space, geometry of solids, nature of shadows hitting three dimensional objects.
This is a Stickup!	**New Skills**: Careful data collection, working with real number data, drawing conclusions from our own data, making models of our experiment. **Topics**: Speed of Sun's path across the sky, triangles and angles, degrees on the sky.
Latitudes and Attitudes	**New Skills**: Using three very different yet sound methods for finding an answer, combining number data and recent experience to draw conclusions. **Topics**: Latitude and longitude, calculating our latitude, angles, triangles, degrees on the sky.
Time Warp	**New Skills**: Telling time, building tools to tell time, thinking about time and relative position on the world. **Topics**: Time and subtraction of times, time zones, Sun's path across the sky with relation to relative time, degrees and angles.
Tilt-A-World	**New Skills**: Combining data with observations, believing what we are experiencing by testing the data in terms of math and models. **Topics**: Value of the Earth's tilt, orbit of the Earth around the Sun, seasons, climates.
Through Thick and Thin	**New Skills**: Building a theory about the changes we have seen all year by using our experiences and data about shape, the movement of the Sun, the tilt of the Earth, the passage of time, and the nature of light, to believe in the changes we have seen all year. **Topics**: Graphing, using tilt angles, calculating area and temperature, wrapping up.



How to Use the Threads of Inquiry

As a teacher, you are probably wondering how to introduce this material into your existing classroom, how challenging it will be, or even how appropriate the material is under the nation's new education reform acts. We will try to address those concerns up front by explaining how the Threads of Inquiry are designed to integrate with your classroom on numerous levels.

First, this curriculum is designed to help your students acquire the skills and confidence needed for an inquiry-based curriculum to work successfully. Built into the curriculum are a number of tools for you to encourage inquiry in your classroom. You also will find sections and a companion document written by an education specialist on topics related to cognitive and social development and aspects of inquiry in the elementary school classroom.

Also, each Thread is broken down into grade ranges/levels of cognitive development, with our motives for the break down outlined in the text and based on fieldwork in partner schools around the country and on current research in education. This allows you to use this curriculum without the additional time factor of having to sort through it for age appropriateness. At higher grades, the age-appropriate sections introduce more abstract concepts and math skills into the students' learning. Simultaneously, the depth of knowledge explored by the Threads is increased. This allows teachers to create a science curriculum which is not only reinforced throughout the student's elementary school career, but which also allows teachers to subsequently re-engage students in these topics at a more intense and sophisticated level.

We have also constructed a set of outside resources related to the Threads for you to examine and possibly include in your classroom. These resources include Internet activities, children's books (both fiction and non-fiction), and folklore connections (including stories, historical features, and cultural activities for the class). Finally, let us stress again that we have designed the text to be flexible enough for you to integrate your own ideas into the framework of the curriculum — in essence, creating a personalized, multidisciplinary inquiry-based curriculum.

Role of Development in the Threads

The Threads are divided into different grade levels, K-2, 2-4, and 4-6. This breakdown respects the different capacities and motivations that children bring to their learning at different ages. The delineations are not rigid, but rather a device to help teachers quickly orient to and focus on concepts that are most resonant with the age group that they are teaching. Some teachers may want to read through the Threads as they are written at other levels to cull additional information and to provide a greater sense of the developmental trajectory of the concepts. Under each Thread there is a section on Developmental Issues. This section discusses how children are differentially motivated and how different ages bring varied developmental capacities to the understanding of every Thread.

The first part of the Developmental Issues section of each level in a Thread discusses developmental motivation. Developmental motivation refers to the best ways to invite learners of certain ages into the material. It suggests patterns for working groups, what angles students might find most appealing, and how children's mental development influences their motivation to learn the topic at hand.

The second part of the section mentions the developmental capacity of the age levels being discussed. Developmental capacity refers to the ways in which the particular content should resonate with and/or challenge different ages. A paragraph in the Developmental Issues section alerts teachers to challenges that children may need help thinking through as well as concepts that are particularly well-suited for this age level. It is important to realize that experience with concepts and ideas helps children learn to understand them. This suggests that teachers should not shy away from presenting concepts that are slightly beyond the developmental level of their students, but that they should support the students' developing understanding with other paths to grasping the concept.

General Developmental Issues and Challenges to Keep in Mind Throughout the ECT Program

Kindergarten to Grade 2

Understanding the patterns of the seasons and the "whys" behind those patterns is in some respects, a fitting task for students. In other respects, understanding the seasons is a challenging undertaking for young thinkers. Knowing how the inquiries presented in the ECT Program resonate with this age group, as well as where they extend beyond the reasoning abilities of this age group, will help teachers deal sensitively with issues of understanding as they arise.

Making observations using one's senses, attending to patterns in one’s environment, and detecting changes and continuity fit well, from a developmental standpoint, with learning in the early grades. Children are learning to reach out to a social and physical world. They are learning how to look carefully and delight in their discoveries. They are often eager to find out how things work in the natural world and ask many questions. They still look to adults to help them answer their many questions. The ECT curriculum taps this natural curiosity and helps children seek patterns in their observations. The focus on learning from one's experience is a natural developmental fit for this age group.

From about age three to seven, children are learning about the appearance/reality distinction. Children learn that things are not always as they appear. Helping children make observations that eventually lead them to question appearance versus reality presents a good developmental fit.

Some of the larger understandings in the ECT curriculum present key challenges for the youngest learners. Understanding in a deep sense that the Earth is moving (not the Sun), and that the tilt of our planet causes the seasons, entails a number of distinct difficulties for young thinkers.

In order to deeply understand what is going on, children need to make a perspective shift. Children need to reason from a model and relate it to the world that they are standing on. They need to shift from what they see in the real world and relate it to a model.

Constructing the understanding that the Earth must be tilted requires reasoning in a "what if?" manner. One needs to hold in accessible memory information about possible scenarios and consider which of those scenarios makes a best match with the information one has observed and the data one has collected. This presents a cognitive load and a thinking challenge better suited to older students.

A challenge for this age group will be finding out that they observe many patterns that they cannot easily find answers to and that there will be many unanswered questions for now. However, this is an important lesson in learning to think as scientists do. There are many unanswered questions in the world and we continue to seek answers as we learn more and more.

In order to accommodate both the readiness and the challenges that the ECT curriculum poses for the youngest learners, the focus in the Threads is on observing patterns in the world around them, connecting to their own experiences, and beginning to learn how recording information can help them extend their thinking about what they see. You will see this focus play out in a variety of ways throughout the threads as written for K-2. In addition, you will also see instances where information is recorded on paper, so that young learners have less to hold in their heads and also become familiar with forms of representation for the concepts being discussed. Downloading (or recording our experiences for deeper learning) some of what needs to be remembered helps young learners make better sense of the concepts in question.

Grade 2 to Grade 4

By second to fourth grade, students are increasingly able to think about abstractions and different perspectives. They can reflect on their thinking and can consider whether their reasoning follows well from the evidence that they have collected. They have already learned a lot about the world in which they live and can use this knowledge to support their reasoning about what the world is like and why things are the way they are. Sometimes their observations lead them to knowledge that fits with scientific views of the world and sometimes it leads them to unscientific views.

By second and third grade, children are increasingly able to use representations and models to reason from. They are still helped by downloading information to external sources so that they are able to focus on thinking, rather than trying to both remember and think about the concepts.

By this age, children are moving out into a broader social world and the world of peers is becoming very important. They begin to question adults and rely on their own observations and inferences to a greater extent. Some children go through a phase where they secretly believe that no one knows quite as much as they do (particularly adults) and may challenge what adults tell them.

The ECT curriculum invites 2nd to 4th graders to explore puzzles and patterns in their world and to make a purposeful link between their own learning and school learning. It encourages them to reason from the evidence that they collect and to come up with their own explanations. This is a good developmental fit for this age. Making a purposeful link between home and school learning is very important at an age when so many children begin to create “boxes” for their knowledge, holding separate their school learning and their own everyday experiences. The ECT curriculum invites them to use their increasing ability to abstract and consider logical alternatives.

At the same time, second through fourth graders will need guidance in reasoning about the puzzles that they find. While they may be able to make predictions and detect certain discrepancies between the data and what they predict, they don't always resolve the discrepancies as a scientist would. They are just learning about how a scientist thinks and so they don't hold the same assumptions in their heads. For example, they might create a customized theory to explain one instance of a phenomenon and a different theory to explain another instance that scientists would consider contradictory to the child's initial theory. Helping students to see how scientists would reason about the event helps them learn not only content, but what it means to be a scientist.

While these students will be able to answer more of their questions than younger students, they , too, will be learning that science is a continuing process of seeking answers. This is an important understanding about the nature of science and is helped when children see that scientists have questions that they cannot presently answer, but seek to answer.

Grade 4 to Grade 6

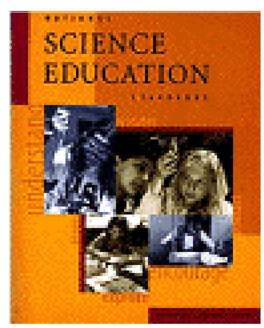
By fourth to sixth grade, students have gained a great deal of knowledge and ability to reason in a logical, hypothetical manner. They are coming to understand many of the "tools" that scientists use, such as the importance of trying to isolate and control certain variables. They are able to hold more information in their heads and while downloading information can still be helpful, they depend less on doing so than younger children.

Fourth to sixth graders are also growing into a time when they are establishing a firm sense of self. They often compare themselves to others, are becoming more introspective, and are developing an understanding of their own uniqueness. With these developments comes an increased concern for risk-taking and standing out as well as wanting one's own forms and instances of expression to be validated. Therefore, teachers need to be particularly sensitive to risks that they ask students to take and to enable multiple forms of expressing ideas and understandings.

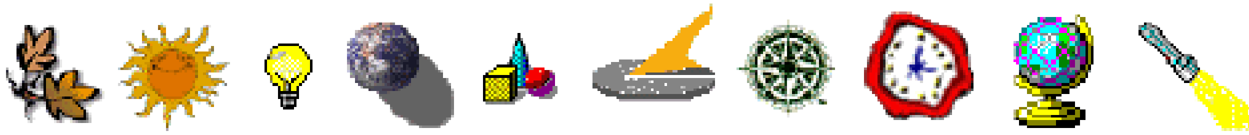
The ECT curriculum invites students to use their logical, deductive reasoning to make sense of their experiences and the related data that they have collected. It invites them to make sense of the world and its mysteries by collecting clues and reasoning about them--an activity that is highly developmentally resonant with this age group.

The ECT Curriculum encourages students to put forth their understandings and theories and signals to students that science is making sense of one's experiences, that theories evolve, and that the process of seeking theories that explain more is valuable. It separates the value of theory and ideas from the person by stressing the process more than whose idea it was. This is a message that is particularly important for fourth to sixth grade teachers to convey to their pupils.

Role of the National Science Education Standards



With education reform happening at so many levels, you may wonder whether or not it makes sense to learn a new curriculum; will it survive? Our research shows that for those states which have reformed their curricula standards, on the whole their standards are reflections of the National Science Education Standards. Therefore, each Thread of this curriculum begins by showing how the National Standards are incorporated. Through this feature, we hope to allow you new freedom in your science curriculum, while assuring you that our program fulfills requirements you are being asked to meet in your school district.



What does a typical Thread look like?

Each Thread has a name and its own icon from the set above. An icon appears as a side tab at the beginning of each Thread.

Purpose: Each Thread begins with a section describing its purpose. The goal of this section is three-fold. First, it provides an introduction concerning how the Thread fits into the overall scheme of the curriculum. It pinpoints the reasons why it is important for students to understand what is happening around them with regards to the Thread topic. Next, this section informs you of how this Thread fits into your classroom with regards to the National Science Education Standards. Finally, this section of the introduction suggests how the Thread can help you introduce vocabulary words which are related to your discussions and which are mentioned in NSES documents as useful for the science curriculum.

You will need: There is a grey box on the right side of the Introduction to each Thread. The first paragraph lists the materials you will need.

The second paragraph lets you know the sort of time requirement you will need to investigate this topic thoroughly. This section describes everything we can think of which will take time in or out of your classroom to fit this curriculum into your classroom time. These include: Does this require a sunny day? Repeated observations on an hourly, daily, or monthly scale? What is the materials-gathering time? Computer time?

Teacher Background: Each Thread contains background information. The background information is *not intended for the student*. It is meant to provide you with data about the topic you are about to explore. Although the Threads are not designed to be vessels of content, it is often necessary for an educator to have a fair grasp of the geometry, physics, astronomy, or other disciplines relevant to the inquiry before feeling comfortable about facilitating the Thread in a classroom. We hope that this section will help you respond to questions from students by prompting other questions of your own geared to stimulate deeper understanding of the basics of the problem. We also would like this section to aid you in designing your own experiences for the students based on how you and they understand the content. With the information in the Teacher Background section, we hope you will be able to seek related themes and connected activities for your class.

This book also offers a list of children's books suggested by K-6 teachers and folklore materials designed specifically for this curriculum. You will find other supplementary activities and assessment strategies located throughout the curriculum. **The Keys to Inquiry**, an important resource on constructivism and inquiry-based learning, can be found in the Additional Resources section of this book.

Grade Level

A grey box denotes the grade level of the Thread you are reading. Lightest gray is Kindergarten through second grade, medium gray represents second through fourth grades, and dark gray stands for fourth through sixth grades.

Developmental Issues

The Threads are divided into the grades kindergarten through second grade, second through fourth grade, and then fourth through sixth grade. This is not a rigid delimitation. Teachers of students on the borders of these groups, (i.e. second and fourth grades), should read both sections of the Threads which apply to their grade. Decide, based on your knowledge of your classroom, which version of the Thread you feel is more appropriate for your students, or you may wish to integrate the two versions.

As described previously, the Developmental Issues section explains our rationale for how the concepts are approached for each grade division, pinpointing how the physical and mental characteristics of children in the age group determine the level at which you would like to pursue this Thread.

Inquiry Introduction

The Thread then poses some introductory discussion questions for teachers to ask their students to get the inquiry ball rolling. The questions suggested in this portion of the Thread guide the class towards thinking about the topic and the set of experiences the topic will provide. It invites teachers and students to reconsider what they know from past experiences and observations.

Inquiry Investigation

Here, the Thread gets into full swing. Students explore the topic through observation, experiences, and analysis of their own experiences. The teacher is there as a guide to their discoveries and to move the students through the different arenas of learning. The text of this section is the most lengthy, as it offers questions, suggestions, and hands-on activities to bring students towards a deeper understanding of what they are exploring.

The use of student journals is highly encouraged for the upper grades, and places where we feel a journal entry should be made during the investigation have been noted in the text.

The Everyday Classroom Tools project utilizes the theories of inquiry-based learning through *constructivism*, which bases students' learning on past experiences and theory building. The National Science Education Standards also stress that the inquiry method be the backbone of science teaching for educational reform. Therefore, the text reads very much like a dialog between teachers and students which emulates an inquiry-based classroom. In the inquiry sections, any text you see in this font is directed towards the teacher. The text in this font is in the form of specific directions, examples of how students might respond to certain queries, or suggestions for further inquiry or projects. Think of this text as the author-teacher dialog, whereas this text is the teacher-student dialog.

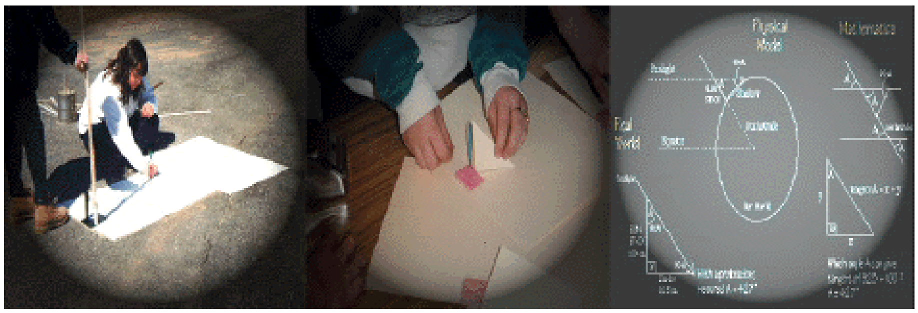
We understand this classroom method may be new for some teachers, and so we provide an additional text guide to using inquiry in the elementary school classroom. Please read **The Keys to Inquiry**, an in-depth look at the practices of constructivism and inquiry in the elementary school classroom. This piece is written by Tina Grotzer, a research associate of Project Zero at the Harvard Graduate School of Education. Her work details the research regarding cognitive development of children, offering techniques for bringing out the best in your students' question asking and answering skills, observation and recording abilities, while its text provides key classroom examples for different grade levels.

The Scientific World View:

- The world is understandable.
- Scientific knowledge is subject to revision.
- Scientific knowledge is durable.
- Science cannot provide complete answers to all questions.
- Science is inquiry.
- Science demands evidence.
- Science is a blend of logic and imagination.
- Science explains and predicts.
- Scientists try to identify and avoid bias.
- Science is not authoritarian.
- Science is a complex social activity.
- There are generally accepted ethical principles in the conduct of science.
- Scientists participate in public affairs both as specialists and as citizens.

— Rutherford and Ahlgren, *Science for All Americans*

The Threads of Inquiry



To Seek or Not to Seek?

Purpose

In this Thread, we will begin our experience with the tools of scientific inquiry. We will be observing our world, inside and outside of the classroom, looking for changes, perspectives, and patterns. We will begin to use measuring tools as simple as our feet and fists and move on to more complex devices such as microscopes and scales. This is the first step in our journey to build learning from direct experiences.

The National Science Education Standards stress that students of all ages should be learning science from an inquiry-based approach. The passing of the seasons and the characteristics of the natural world should be observed and known, as well as how a changing environment affects life on the Earth. Students should become familiar with the history and nature of science. The Standards also stress that recording data and measuring specimens from nature are crucial for the science student. The vocabulary which can be used to help us talk about our experiences are words such as observe, experience, curious, theory, pattern, change, detail, evidence, data, nature, science as inquiry, sight, hearing, touch, smell, and taste.

You will need: journals, pencils and crayons, plastic sample bags, microscopes, scales, and rulers.

The visits outside or around the school will vary according to the ages of the students. We recommend that there be enough time during a session for each student to draw a certain aspect of his observations and/or write a short description of the area he viewed (or even a list of the relevant features observed). Repeat visits to the sites need to be made at intervals of about three weeks. Additional time will be spent talking about what change the class has seen between visits. Gathering materials for this Thread should not be difficult, as most of the equipment should be available at the school.

Teacher Background

Ultimately, the purpose of this adventure is to watch Autumn happen, although we don't want to say that from the start! We want to invite inquiry into the classroom by *leaving* the classroom! Looking around outside will reveal many interesting things about the world around us. The trees will soon change, relying on their sap and ground water to survive during the cold months. This process can be seen during the next few months as the leaves change from green to brown and then detach from the tree entirely. The colder temperatures and decreased sunlight will cause many plants to die altogether. Most plants will develop seed pods which will fall and provide a new generation of plants in the spring. Over time, certain insects will become active while others will disappear. The fur on some critters gets thicker, while other animals go into hibernation.

Having students make observations on this first day is key. There is no book telling us what the outside of our school looks like. We must explore it ourselves. We must look around with care, draw what we see, describe what we see, and keep a neat record of this world outside our classroom. When we bring the students out again in a few weeks, we need to be able to return to these same spots outside and observe again. There will be some changes, and we will find as many of them as we can. If your school is surrounded by asphalt, a walk to a park or garden will work quite well.

Collecting samples to bring back to the classroom will, hopefully, also bring the inquiring mind into the classroom. Using tools such as microscopes and scales to measure and record what we have found will allow us to keep more than just pictures and words from our observations. We can use this empirical evidence later when we compare our first finds to those we pick up on later visits. Bringing data inside also is a good way of demonstrating that observation is more than just looking around; it is learning about something which is in front of you in any manner which is possible: touching it and smelling it, as well as weighing it and measuring it.

The skills of good record keeping also should be introduced with this exploration, perhaps not on the first trip out, but on the second. We may think, "If only I had made a better record, I would know what had changed." Find moments during the investigations to ask your students these questions: Why should we date our records? Could we record in which direction we were looking? Does the time of day make a difference in what we see?

For the teacher, it is important also to realize that here we are asking things of the students which may have never been asked of them before. There is an atmosphere we create in inquiry-based learning which is most likely unfamiliar to them, and we should be sensitive to that. We are asking our students to do most of the talking, instead of us, and we also are not giving many answers -- *they* will find them. We are only collecting data and comparing it with what we gathered before. We are learning how to observe the world around us and make some inferences about what we see. We need to make students comfortable with this, instill some confidence in their ability to observe, gather data, and make connections. Students in this age group will not be used to having this much control over the learning process, and we need to understand that it will take time before they grow assured enough to begin probing deeper into patterns and predictions.

Within two months after the beginning of school, autumn's changes will become readily apparent in the world outside of the classroom. By then, we should have established a comfortable environment for inquiry and students should be at ease with exploring everything they encounter, from math to moths, using the tools of scientific inquiry.

> "It is here we must begin to seek the wisdom of the children."
> — John Denver, *Rhymes and Reasons*

> "Well, what is the answer? But, what, then, is the question?"
> — Gertrude Stein

> "An investigative or inquiry-based approach...can indeed help students learn the important concepts, processes, and habits of mind of science, and also something more. The students experience firsthand what science is—an ongoing, complex enterprise of the mind, conducted collaboratively with practical consequences for human welfare. They learn this by doing what scientists do—applying intellectual processes to the task of producing and testing knowledge about the natural world. Students are not only introduced to the body of ideas called scientific knowledge, but also themselves become thinkers about the unknown and builders of knowledge."
> — John Layman, *Inquiry and Learning*

Kindergarten through Second Grade

Developmental Issues

This Thread resonates with kindergarten through second graders in many ways. It invites observation of change, a concept that fits well with students' own explorations. They have been growing and changing a great deal themselves, and this activity invites a natural extension of noticing such patterns in a broader world. There are also natural links to using all of our senses, as well as learning how to frame questions.

Children in this age group are often capable of and interested in using their emerging understandings of logic and order in helping them make sense of the world. For example, they often enjoy sorting objects into sizes or classifications and watching cause and effect. They may enjoy starting elaborate collections of things. This Thread offers opportunities for them to do all of these things within the framework of learning to observe their world and record what they find. It will provide ways for them to build their increasing knowledge of words and numbers along with the skills of scientific inquiry.

In this activity, this age group will find out that they observe many patterns that they cannot easily explain. There will be many unanswered questions after this investigation. Beginning the process of experimentation without knowing all of the answers is an important lesson in learning to think as scientists do.

Teachers will need to help children consider the difference between cause and effect and correlation in concrete instances. For instance, some children might think that it is the leaves turning color that makes them fall from the tree. What are the key causal factors and what are correlational ones? The Everyday Classroom Tools Project can help all students think deeply about key causal factors (the tilt of the Earth resulting in shorter daylight time, thus less warmth) and the multitude of correlated effects (birds flying south, leaves dropping, plants making seed pods). It is unlikely that the youngest children will be able to make all of these connections, but their teachers can help them see particular instances when a pattern is correlational as opposed to causal (i.e. The leaves turning color will not "make" the birds fly South, the increasing cold causes both.)

Inquiry Introduction

Many of us have questions about our world. What makes a day happen? What are the stars? How do birds fly? Why is the sky blue? Where do we usually go for answers? Many students will say their parents. Where do parents go for answers? Many will say to books or TV. Where did books and TV get their answers? And so on until we realize that someone somewhere – and some *when* – discovered those answers because he or she had the same questions. If there can be a someone who had the same questions as us, doesn't it follow that if he found the answers, so can we? All we'd have to do is think of a plan for finding that answer. It would probably start with observing the richness of the world.

Inquiry Investigation

What does it mean to look at something? How many students in the classroom could tell you what the sky looked like when they got to school this morning? Why is the number so few? Is it important to observe the world around us? Why do we only do so when there may be danger, such as crossing the street? Let's pick a question such as what does our world look like right now and go answer it. How do we start? Well, first we go outside!

Outside the classroom is a wealth of information. Where do we begin? As explained in the background information, we want the students' data to show the real changes as we go from summer to fall. So, once outside, you may want to encourage the students to look at their world closely, giving examples of the trees and plants as good things to draw or record. They should feel free to observe whatever they wish, as long as the observations of plant life are present somewhere.

What does the sky look like today? Is it a nice day? What colors can we see around us? How big is a tree compared to a grass blade or to us? What things could we pick up and which things are too heavy? Are there bits of our world which we could bring back to the classroom? What might we be able to learn from them? What tools could we use to learn more about them? It's a good time to gather objects. Plastic lunch baggies for collection should be handed out with journals and pencils, and students should be encouraged to record their observations in whatever manner they understand.

In the classroom, break the students into groups seated at different tables. Let's spill the contents of our baggies on our group's table and look at what we've got. In what ways could we sort these objects? What things about them are the same or different? Size, color, dryness, function, and shape are all good ideas for categories.

Encourage students to try all different ways of sorting. Older students could record the number of objects which fit into each group or fit each category. Younger students could show you what they have done once they have sorted in one way, and then you might suggest they try to find yet another way to sort their collections.

What is change? Does the world outside of our classroom change at all and, if so, in what ways? How would we see those changes? How could we know for sure that things had changed? Would asking our parents about our observation site in the school yard give us any answers? Why not? The answer is that they are not here and it was our observation not theirs. Hopefully, students will see that they would need to go back outside and check to see if things change.

The next time you take your students outside, bring them to the same spot they went to before. Ask them very specific questions, such as "Were there that many leaves on the ground last time?" and "Did that plant have seed pods?" They probably will not have made a very careful record of their first visit and may not be able to answer definitively.

Here is where we can discuss the importance of recording. This is not to say we need be boringly precise in our drawings and text. This is just to point out that had our questions been very explicit, our records should have been as well. However, our questions were broad, and so were our discoveries. But what if we had wanted to know the answer to a question such as "What will happen to the trees?" Where would we start?

We could pick a tree out here which we could watch all year. We would make careful records of it when we came outside. We could even name our tree and collect leaves from it. We should never fail to observe the world around the tree. Observing just a tiny piece of our view makes it difficult to talk about the whole view. We should recognize that there is more to observing than just looking at tiny bits. Choosing some good times to repeat this Investigation, such as the first snow or the coming of spring, would be beneficial for getting a good chronology of the changes taking place outside.

> "Remember to always think for yourself and listen to your ideas, even if they sound crazy at first."
> —Sarita M. James

> "Trust your feelings, Luke."
> — Obi-Wan Kenobi, *Star Wars*

Second Grade through Fourth Grade

Developmental Issues

Students in this age group are growing increasingly able to think about abstractions. Inferring abstract patterns from concrete instances, as called for in this Thread, fits well with their developing reasoning skills. They can reflect on their thinking and can consider whether their reasoning follows from the evidence that they have collected. While second to fourth graders have the skills to answer more of their questions than younger children, they will find that science is a continuing process of seeking answers, an important lesson for all learners! Teachers can help students of this age make a distinction between cause and effect and correlation (i.e. The leaves turning will not make the birds fly South. Instead these are correlated and the increasing cold causes both.) Teachers can introduce the words, "causal" and "correlational" to help students think about how events are related.

Often children at this age want to be given "real" and "grown-up" things to do. Beyond this, their growing cognitive capacity enables them to hold many possibilities in their minds at once and to consider alternative explanations and scenarios. Therefore, for this age group, we will approach this Thread very seriously and talk more about mysteries and puzzles — the answers for some even we do not know! We will tell them we are stepping back to explore their questions with the tools we have available to us. Consider having the students work in groups for investigation. Exploring the ideas of others is an important source of learning and capitalizes upon this age group's budding social interests.

Inquiry Introduction

Close the window shades or drapes (or whatever) and ask the students some questions. How many of you students can tell me what the sky looks like right now without peeking outdoors? How many of you think it is cloudy? Those who say "yes" should all meet at one place in the room. What about sunny? They should go to another part of the room.

Address each group in turn. What clues or evidence did your group use to make this claim? Did you guess? Is it OK to guess? Sure, but it is best if we made an educated guess or one based on clues we put together. Making an educated guess means we are thinking and puzzling. How could we know for sure what the sky looks like right now? Look at it, of course! Open the shades. Who was right? What is the evidence?

Close the shades once more. Ask students to tell you something about the ground near a big tree or other obvious object in the yard. How are we supposed to know that? you may hear. Well, the shades were open and the world was there to see. But you asked us about the *sky*! Here is another key element about observing our world. So often we simply look at the one thing which is immediately important but neglect to view the rest. For example, we look both ways at a cross street, because we don't want to get hit by a car or bicycle. This is a very good reason to look around, but why not just look around because the world is pretty cool?

Inquiry Investigation

Outside, what things can we see that are alive? What things are not alive? What things may change in a year or a week? What could we watch through the year that might go through some clear and obvious changes? Trees are a good choice. We could even take a photograph or draw a picture of what it looks like now. How long do we think it might take before we see some kind change? And what kind of change might that be?

What things can we find on the ground? Seeds? Dead leaves? Weeds and flowers? Will these be here in a week? In a month? Why or why not? Have the groups collect those things on the ground around the tree, keeping a record in a journal. How do these things relate to the tree, if at all?

What other things in this school yard could we watch? What about the wildlife, if there is any? What kinds of critters seem to live around this tree? What do these critters do in the yard? Bees which gather pollen and help flowers grow are an example. Will bees be around when the flowers are gone?

Return to the outside area around the tree (or wherever you started) and repeat the gathering of data by collecting bags of samples and making pictures of the area. In the classroom, create stations with scales and rulers. Allow teams with their data collection bags to analyze what they have in terms of weight, size, color -- whatever they decide are characteristics. They should keep this data in their journals, maybe even staple or tape their baggies on to pages of the journal. Have students explain their findings to the other teams.

How might these findings change over time? Let's plan to go outside again and test some theories about what we think may happen out there.

Fourth Grade through Sixth Grade

Developmental Issues

This Thread may seem like a silly exercise to students at this age; they do not like to look stupid or take risks, especially in the sixth grade. At this age, students are establishing their individuality and gaining a sense of who they are. An important message this lesson can convey to them is that multiple perspectives and observations help us to have a fuller, increasingly objective account of what is happening. Stressing the importance of different kinds of perspectives and observations increases the level of engagement of all students and suggests to them that it is okay to be yourself. Therefore, this investigation should not seem like a race or a contest. However, as this is the very first introduction to Inquiry-based learning for many of them, encouraging independent thinking within a group situation is key.

These students also are becoming increasingly introspective. This is a good age to do related writing activities focused on topics, such as how one feels about the changing seasons. Perhaps letting them go out with a journal is a more private means of letting them explore. Talking about what is written is often easier than asking them to call out. As students grow more accustomed to inquiry-based approaches, their verbal participation should increase. For teachers who already use inquiry-based approaches, it's likely that your students are less reticent than others.

Inquiry Introduction

What was the sky like yesterday? How many birds live in the tree across the yard? How many cars were parked in the lot when you got to school? How are we supposed to know *that*? What was the Moon like four days ago? When will a hurricane hit Florida? How do cancer cells grow? What is a tadpole? All of these things require observation.

In teams, have the students pick one of these questions above and brainstorm about the things one would need to do to answer them. The key to answering these puzzles is knowing that all of them require watching something for a period of time. For example, if you looked in a pond and saw a bunch of tadpoles, you would think they were the local critters in the pond. If you looked again in three months and they were gone, you might be very confused. Where did they go? If you looked and found them nowhere, you would be alarmed, perhaps, especially since there are now a bunch of frogs hanging around. Did the frogs come in and eat the tadpoles? Of course not. Everyone *knows* that tadpoles are baby frogs, but *how* did someone ever learn that?

You need to watch carefully and repeatedly the changes that happen around you and be aware of cause and effect. You also need to isolate the important details from the fluff. What things do you need to watch in order to discover if a hurricane is going to hit Florida? Do you need to watch soap bubbles in your sink? No, you would need to watch the weather reports and storm fronts. What if you wanted to watch the seasons turn from summer to fall? Would you watch a shoe? What would you watch? What kind of data could you gather?

Inquiry Investigation

With journals and plastic bags, let's begin exploring the world outside the classroom. What are the things out here which could change first? Which things probably will not change until later? Are there things which may never change in our life times? What could we collect as evidence of what we are seeing out here? What are we seeing out here anyway? In your journals, write some thoughts about the world out here. Pick a spot you want to watch for a while during the year that you think will change fairly impressively. Draw it as you see it and gather some bits from the area that represent what you see. Do you have any predictions about which parts will change and which will not? Why? Why not?

Why is it important to pay attention to things in our world? What if you never looked both ways when you crossed a street? What might happen to you? How about if you never checked the weather from a window or door before you went out? There are some practical aspects of keeping an eye out on the world, aren't there? Are there things you have watched grow for your own pleasure? Are there things you have checked in on every once in a while to see how they are doing, like a chicken's nest, tadpoles, a sleeping baby sister, or crystals?

On what scales do things change? Is change always obvious to our unaided eye? Does the Sun change? Do the wings on a gnat change? What tools would we need to observe these kinds of changes? Using a microscope for tiny specimens is possible in an elementary school. Using a telescope for more distant changes may not be. Inviting an astronomer with a telescope and sun filter would be a good means of watching the Sun. However, do not try to do this without an expert. Looking at the Sun through a telescope will instantly, painfully, and permanently blind the observer!

Talk to the students about what the tools of inquiry are: Asking questions like these to fuel understanding, being curious and using science to guide you to answers, is known as the Spirit of Inquiry. There are many things we could ask here about the world outside, such as how do trees survive the winter or where do the birds really go and when? Let us make some lists of questions we would like answered about changes in the world. For how many of these do we really think we might find answers?

How do people find answers to questions? Many people ask other people or read books. Others look on the Internet or watch a television program about it. And still others, scientists, create ways of discovering answers by careful observation. We will be scientists, by going outside and experiencing things for ourselves, so that when we do find answers, they are our own. We must be able to think about things and not be afraid to ask questions about them. Without a question, there is no inquiry. Without inquiry, there is only reading someone else's data from books.

Hello, Sun!

Purpose

In this Thread, we will examine the passage of time by watching the world change outside our classroom. The Sun will seem to move across the sky in a steady manner throughout the day. This will allow us to begin thinking about the movement of either the Sun or the Earth as well as the shape of the Earth so that the motions make sense. The National Science Education Standards call for students to become comfortable with objects' properties of size and movement, an example being the Sun. Students should learn that the Sun *appears* to move around the Earth, but in fact it is the Earth spinning around on its axis while the Sun remains stationary. This Investigation allows students to explore what the NSES refers to as "technological design". The vocabulary that can be integrated into this Thread are words such as Sun, Earth, day, night, spin, axis, arc, model, angle, sphere, and degree. For a new approach to learning some of these vocabulary words, visit **Word Lore**, an appendix dedicated to exploring the history of words pertaining to this curriculum.

Teacher Background

The easiest way to see time passing is with a clock, but what made us aware of passing time before clocks? The motion of the Sun is the key here, and most students do not know what that motion looks like.

You will need: chalk or wipe board and chalk/markers, easel, roll paper for easel, pencils, journals, crayons, adhesive yellow dots or BINGO markers.

The class will initially need a sunny day for this and will need to repeat measurements from the earliest time possible in the morning until school lets out in the afternoon, at one hour intervals. You will need to locate the direction South outside in the yard. In the classroom, you may want to spend several class periods spanned over a week thinking about the data you've collected. There are few tools required, so materials gathering for the investigation is minimal.

We know that we are a small planet shaped like a ball in orbit around a huge star 93 million miles away. This star we call the Sun, and it is an enormous ball of very hot gas. This star is so large, that even from this far away, its light can reach our planet. Sunlight is radiated from the Sun in all directions, and we are only a tiny planet in the way of a tiny bit of that sunlight. Therefore, we get light from what appears in the sky as a small disc in a certain direction. If we were very close to the Sun, that orb would seem larger. Why do we feel warmth all over the land during the day? Well, that is because we have a lovely atmosphere to keep us warm like a blanket. Why then do we feel cold in the winter? That will be explored in a later Thread.

There is motion we can see on our world. In some respects, it appears that the Sun circles the Earth. Greek philosophers speculated about our world and its geometry and decided that it is the Earth which is turning on its own, making things appear to swing past it, outside of it. This is similar to being on a carousel and watching your family rush around you, even though it is you who are moving. To prepare ourselves to model the Sun, it would be good to first explore some alternative approaches to looking at the world around us. This requires thinking flexibly. Now would be a good time to introduce puzzles, riddles and optical illusions, to help us think about the importance of opening up our minds to different ways of seeing the same thing.

The movement of our Earth is very uniform, making the Sun rise, arc overhead, and set at the same speed everyday. This speed is our spin time, or day, of 24 hours. For students, the term "day" is more like the daylight time. Confusion between “days getting longer” but “days are always 24 hours long” can happen. Begin to refer to these times as daylight time and spin time, to ease communication among your students. In fact, perhaps we should consider inventing our own terminology for these two concepts in class.

As part of the ECT curriculum, we offer some lessons about how ancient and historical cultures used observations similar to those the students will make in the Threads. For *Hello, Sun!*, we’ve included background information and classroom activities in the Additional Resources section relating to how Scandinavians one thousand years ago used the Sun to tell time. We call it **Telling Time Without a Clock**. [Note: The Daymarks project is also relevant for the Thread called *This is a Stickup!*]

> "It is possible to store the mind with a million facts and still be entirely uneducated."
>
> —Alec Bourne, *A Doctor’s Creed*

Kindergarten through Second Grade

Developmental Issues

The purpose of this Thread for this age group is to emphasize the joys of wondering about our world and learning to look for change and patterns carefully. It introduces the skills of question asking, communicating ideas in speech and drawings, and manipulating objects. Students will learn about the Sun as our light and heat source and about our world as having a regular time pattern, which can be observed from the simple motion of the Sun.

This Thread is not intended to impose on students of this age the model of a turning spherical Earth past a distant steady Sun. Research shows that the average five year old is just learning how to envision images in his or her mind and to manipulate those images (for instance, thinking about how to walk to school and then reversing the route in one's mind). However, constructing images that require shifts that the child has never experienced, thinking about positions of objects in the future (beyond yesterday, today, tomorrow), and holding a dynamic model in one's head to reason about it, is challenging for students of this age.

It is important to realize that experience with models and analogies helps children learn to understand them. Teachers should not shy entirely away from presenting concepts that are slightly beyond the developmental level of their students, but that they should support the students' developing understanding with other paths to grasping the concept.

Inquiry Introduction

What is a day? Why is it that we know when a day has passed, or what time of the day it is? What are the things we look for to tell us about the time of day? Or when we are tired? Hungry? Cold? Are there things which always happen at a certain time of the day? Students may want to draw a day (allow yourself time to write a brief narration for each drawing based on their verbal description.) Are they thinking only about daylight time? Do any of them describe a day as more related to the spin time perspective?

Is there any way we can think of to see that a day is passing? Many students will suggest the clock. Tell them this is the modern way, but what about when people didn't have clocks or watches? Does anything change during the daytime which isn't a clock? If no one suggests the Sun, lead them to think about the world outside the classroom. When it is day, what does it look like? This question will seem odd to the students without a contrasting frame of reference. Ask them what the night looks like, then return to thinking about the day. The Sun will enter the discussion now, if it had not already. You should now ask again what happens during the day to make it become night. Can we see that happen? What would we need to do first? Go outside!

Inquiry Investigation

Outside, you should bring an easel with paper and a marker. Without mentioning the direction South, you need to make everyone face South (or North if you are in the Southern Hemisphere). This is important for the observations. While you are doing this, you might want to talk about why it is important that everyone face the same direction (without talking about South) when you are all observing the same object. Facing south is important because in the continental United States, the Sun is in the south at all times. You should not mention this fact at this time. What is important is that everyone should be able to talk about the same viewpoint. Otherwise, imagine trying to talk about a pillow on your bed if everyone else is looking at your door. It will be hard to do unless you have everyone looking at your bed first.

You should then draw the view ahead of you on the paper on the easel. Ask everyone if the details are correct. If not, what should be changed or added? It is the morning during this first observation, and the Sun will be over everyone's left shoulder. Our shadows will be to the right of our bodies. Just noticing that they have a shadow is fun for this age group. Later Threads will provide more time for your students to explore this further.

Ask the students some questions. Where is the Sun? How high is it in the sky? Can everyone think about tree heights or house heights? How about where the Sun should be in the picture? Could we tell from other clues? Some will feel the Sun on their left cheek, and say that is a clue. Few may make the connection between the shadow on their right and the Sun on their left. (This is a great connection which will be explored deeply in later Threads.) Draw the Sun on the easel.

We could, out here in the warmth, talk about our Sun and the heat and light it gives us. How far away do we think it is? What is it made of? How big is it? We don't need to know the real answers for this. We should just be thinking about this great Sun of ours and how much it can affect our world down here.

Return with the easel to the classroom and try to ask where they think the Sun might be in an hour. There will be wild guesses, and that is part of the fun of asking questions in a wondering scientific spirit! They could mark their guesses with mini sticky notes or dots, if you wish.

Return with them every hour to make another drawing. Maybe they can take turns helping you draw the Sun into the easel drawing. How did the guesses turn out? Does anyone have a theory about the movement? Where is the Sun going? What happened to the shadows?

After a few more observations, a definite shape is appearing in the movement of the Sun. This shape is known as an arc, but for the purposes of this younger age group, you can call it whatever you wish. In fact, it would be a good time to compare this shape to other shapes around their world. Some classes in the past called this shape a rainbow, a frown, a big belly, and a bridge. What do they see in this shape? Could they take this shape and draw it in their journals? What do they see? What else can they make from that shape?

The aims of General Science are mainly three:

• 1. To give the student such information as to enable him to understand and interpret his environment.

• 2. To develop in the student the power of observation and teach him to reason from cause and effect.

• 3. To stimulate scientific curiosity.

— Pulvermacher and Vosburgh, *The World About Us*

Second Grade through Fourth Grade

Developmental Issues

Second to fourth-grade age children are better able to reason more time-related concepts, consider two or more variables in thinking about a problem, and begin to plan things for the future. Their skills in dynamic imagery are developing as well as their ability to hold more information in their heads. This makes it possible for them to hold and manipulate the position of images in their minds. This is key to concepts such as predicting from observation or thinking about the movement of two objects, the Earth and the Sun. This Thread will focus on these ideas as directed by our observations. Since students at this age are able and enthusiastic when it comes to reading and writing, an emphasis will be placed on recording data and sharing it with others. On a social level, this age group is typically interested in teams and other social groupings. You may want to consider allowing for this in the investigation, creating teams of illustrators, time keepers, or instructors. It may help students become comfortable with the atmosphere of inquiry-based learning.

Experience with models and analogies helps children learn to understand them. Teachers of students at this level should introduce them and should not shy entirely away from presenting concepts that are slightly beyond the developmental level of their students. Look for ways to support the students' developing understanding with a number of alternative paths to grasping the concept as well.

Inquiry Introduction

Where does the Sun go in the evening? Why does it seem to rise in the morning? What is happening? What is a day for us? We should think more about the outside world and how it knows about a day. Without a clock, what could we look at to know about a day? How could you plan such an experiment? What are the important things to plan when you are about to observe something? How long would it take to get a good idea about what was happening? How would we keep a record of what we saw outside?

Inquiry Investigation

Outside, you should bring an easel with paper and a fresh marker. You may also want students to bring out journals. Without mentioning the direction South, you need to make everyone face South (if you are in the continental United States). This is important for the observations. While you are doing this, you might want to talk about why it is important that everyone face the same direction (without talking about South) when you are all observing the same object. Facing South is important because in the continental United States, the Sun is in the south at all times. You should not mention this fact at this time. Children at this age should be comfortable with left and right, and can use these words to think about the direction of the Sun. What is important is that everyone should be able to talk about observations taken from the same viewpoint. Otherwise, imagine trying to talk about a pillow on your bed if everyone else is looking at your door. It will be hard to do unless you have everyone looking at your bed first.

What needs to be drawn on the paper? Why should we be so careful about getting our view on the paper? We should think about the fact that we are all about to have an experience outside, and if we want to share it with other people, we should really make sure we've got a good recording of our experience.

Should we look at the Sun directly? No, this will harm our eyes. Even glances are not even healthy. How else could we describe where the Sun is? Some will feel the Sun on their left cheek, and say that is a clue. Others might make the connection between the shadow on their right and the Sun on their left. (This is a great connection which will be explored deeply in later Threads.) Where is the Sun with respect to our bodies? To the school? To that tree over there? How does it feel on our faces or arms?

Now, let us leap into another arena of thinking and ask where on the two-dimensional drawing of our view would we put the Sun? We need to make the connections between the representation of objects on the drawing and the actual objects themselves which are outside in the world. Does everyone have a thought about this, and can they explain it to others? Draw the Sun where everyone agrees it should appear in the picture. Drawing in journals also might be a good idea. Return to the classroom.

In the classroom, talking about what a model is would be a good way to link these two experiences. In the real world, we saw a Sun with respect to our position out in the world, and with respect to the positions of other things out in the same world. The drawing, however, contains our viewpoint, without *us* in the picture. It is a model of the world around us, and we are not in it because it is what we saw *around* us. What is the shape of this model compared to the shape of our world? Is it still an OK picture of what we saw? When we were outside, it sure looked like our view. How is our drawing different from the real view? Think about the three dimensions of the world around us and how paper limits us.

What will happen in one hour? Anything? What will our view look like? Will we need to draw a different picture of the school yard? If not, what will be different in the picture, if anything? Perhaps here the class could break into brainstorming teams to think about where the Sun might be in one hour and why. They should prepare an explanation for the other teams.

Return with them every hour to make another drawing. Maybe here is where teams might help keep records and draw the Sun on the easel view. How did their predictions turn out? Does anyone have a theory about the movement? Where is the Sun going? What happened to their shadows? Can those same teams back in the classroom think some more about the movement they have now seen and how it might be reinterpreted?

After a few more observations, a definite shape is appearing in the movement of the Sun. This shape is known as an arc, but you can call it whatever you wish. Children at this age are really broadening their creative skills, and having them think up their own name for this shape would be fun for them. Some classes in the past called this shape a rainbow, a frown, a big belly, and a bridge. What do your students see in this shape? Could they take this shape and draw it in their journals? What shapes can be made from it, half-circles, circles?

What reasons can we think of to explain why the Sun is making this shape? Do we think that the Sun is really moving around the Earth? Many will come to your class already having been told about the spinning of the Earth, but they will not be able to explain it well. Ask them if they could explain the movement of the Sun with a spinning Earth. Is it important right now that everyone believe the Earth is spinning? No, not really. It is important only that they have had this day-long observation and been able to model it in the classroom on paper. You could ask them to try to get up with a group and recreate their observations in a play, where one person (the Sun) walks around another person (the Earth) during the day, and also where the Sun person is still and the Earth person slowly spins.

So, where does the Sun go in the evening? Could we draw it or write about it somewhere? Could we interview other classrooms who have not had the same experiences as us and see what they think? What about classes who have had the same experiences as we did outside? What do they think? Many will say the Sun goes to the other side of the world. Ask them then what is it like for people on the other side of the world when it is day for us? Can anyone point to a place on the globe which is having night right now? The Internet has a database of live cameras set around the world. Finding the country your students chose and looking at a real “live” picture will help solidify their theory and strengthen their resolve. See page 84 for a list of good Internet sites with live cameras.

Another way of enforcing this experience is to make a Noon Line in your school: either in your own classroom, if we face South, or in a friend's classroom across the hall. For instructions, please see the Additional Resource, **Telling Time Without a Clock**.

Fourth Grade through Sixth Grade

Developmental Issues

Fourth through sixth graders are increasingly able to abstract, reflect, and put one's self into another situation. They are able to reason about time more flexibly. They can manipulate images in their minds and can coordinate the dynamics of more than one image. They also can entertain the possibility of future events and think about hypothetical outcomes. These students are also making connections between what they are experiencing and how it affects their lives; how situations in general can affect lives in general. They also can consider different scenarios and envision whether these fit with their observations. This combination allows us now to explore the passing of the day with respect to objects in motion in a three-dimensional world outside of planet Earth and also to think about experiences happening for people in different places. Also, the level of math acquired by this age lets us talk about our experiences in another language, the language of geometry and numbers. This Thread will present the two theories of the Sun's motion debated by the geocentricists (believers in an Earth-centered Solar System) and heliocentricists (believers in a Sun-centered Solar System). Using the different positions of the Sun during the day as they relate to different positions in time and space, we will probe the data for theories and make models of what we have postulated.

Inquiry Introduction

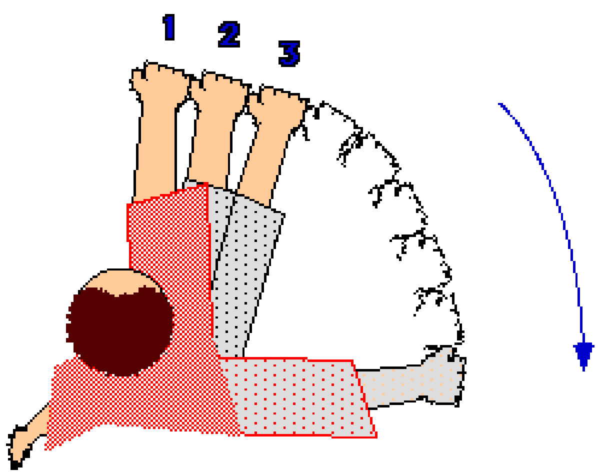
The passing of a day has long been known and measured to be what? 24 hours. But what does 24 hours represent? How could we watch that happen without a clock? What is happening outside which plots the length of day and night?

Inquiry Investigation

Outside, you should bring an easel with paper and a fresh marker. Students should bring their journals. Also bring a navigational compass (or enough compasses for the whole class). What time of day is it? Without having already known it was morning, are there any clues around you that might tell you the same thing? How far around the world can we see with our eyes without turning our head?

Ask the students some questions. Which way is North? How could we find out for sure? If a certain direction is North, which way is East? We always learn East is to the right of North. If everyone faces North, East will be on our right hand. This will help ease the perspective problem. The question is, how easily can we see the Sun when facing the North? Have everyone face the South. Which way is South? Is it easier to see the Sun in our view now? OK. We will face South, then. Could we draw that view? Having everyone bring out their journals is a good exercise here. They can all draw what they are seeing. Ask them what they have done by drawing the world. Is our drawing truly the real world? It is a flat model. How does it compare to the world around us? Is it a good representation of the world? Would someone from another school be able to recognize trees and houses as such in our drawing? Also, draw this view on the easel paper.

Should we look at the Sun directly? No, this will harm our eyes. Glances are not even healthy. How else could we describe where the Sun is? Some will feel the Sun on their left cheek, and say that is a clue. Others might make the connection between the shadow on their right and the Sun on their left. (This is a great connection which will be deeply explored in later Threads.) Where is the Sun with respect to our bodies? To the school? To that tree over there? How does it feel on our faces or arms?



How high is the Sun? How could we measure that? With a ruler? There is a very easy technique called "fist measuring" which can help us without having to use anything but our own bodies. All you need to know is that 90° is the angle difference between holding your arm straight out to the side and straight out in front of you. All you need to do is stand still and put your arm out in front of you at eye level, with your hand in a fist. Close one eye. Carefully begin moving your arm stiffly, watching and counting how many fists you can line up side by side until your arm is 90° away from where you started, or straight out to your side. Use things around the yard as guides to help you count those imaginary fists. The figure helps you see what we are describing. Dividing 90° by the number of fists you counted will give you how many degrees your fist covers! (Hint: In case you are not sure of your answer, an average fist covers 10° on the sky. Your value should be close to this.) Similarly, you can try to calibrate your finger! Try this outside (your finger held at arm's length will cover 1° on the sky.)

Now, let us imagine where on the two-dimensional drawing of our view would we put the Sun? We need to make the connections between the representation of objects on the drawing and the actual objects themselves which are outside in the world. Does everyone have an idea, and can they explain it to others? Draw the Sun where everyone agrees it should appear in the picture. Use the fist measurement tool to relate the Sun's position to the horizon, to nearby buildings and trees, and perhaps to due south. Return to the classroom.

How would we go about making some good observations of the Sun to understand what is happening in a day? Most students will tell you to go out every so often and check. Why? What might change? Does our world change? How has it changed since spring? How will it change in four months? How will it change in five hours? How have we changed in a year? The changing world means we need to keep an eye on it. What is the scale for watching the Sun move in a day? If no one else does, suggest that observations be made every hour. Have the students devise a plan for carrying the easel and markers and making sure journals get collected for observing outside. Does anyone have a clue about where the Sun might be next? Let's all make some predictions with accompanying reasons in our journals.

Return with them every hour to make another observation and drawing. Where is the Sun now? Is it noticeably different? How many fists up in the sky is it? Maybe they can help you draw the Sun in. How did their predictions turn out? Does anyone have a theory about the movement? Where is the Sun going? What happened to their shadows? Many will come to your class already able to tell you that the Earth spins, but they will not be able to explain it well. Ask them if they could explain the apparent movement of the Sun with a spinning Earth. Is it important right now that everyone believe the Earth is spinning? No, not really. It is important only that they have had this day-long observation and been able to model it in the classroom on paper and then later on the board as a geometrical model. We can then talk about our experiences back in the classroom and think of some good explanations for what we saw.

So, where does the Sun go in the evening? We could interview other classrooms who have not had the same experiences as us and see what they think. What about classes who have had the same experiences as we did outside? What do they think? Many will say the Sun goes to the other side of the world. What is it like for people on the other side of the world when it is day for us? Can anyone point to a place on the globe which is having night right now? The Internet has a database of live cameras set around the world. If you are able, access a site and find the country your students chose. Looking at a real "live" picture from that place will help solidify their theory and strengthen their resolve. See page 84 for a list of Internet sites with live cameras.

After a few more observations, a definite shape is appearing in the movement of the Sun, if you use each Sun plot as a dot in an outlined shape. What shape is emerging to describe the movement of the Sun? This shape is known as an arc. How might we extend this shape into a bigger shape? Draw this arc high on the board, leaving room on the sides and the bottom for thoughts about the larger shape of this arc. Ask them if this is the shape they saw the Sun moving in. Students will see a semi-circle and a full circle, some may even be silly and make some squiggle. Perhaps they should put their bigger shape in their journals and give it a name.

Can anyone think of a reason why the Sun is making this shape? Is the Sun moving? Do we think the Sun is moving around the Earth in this shape? Where in our drawing on the board is the Earth? If this is too hard to think about, where then were we in the picture? If the shape were a semi-circle, what would happen to us? Would the Sun go right through us? What about the other side of the Earth. Do people live there? What would happen to their day if the Sun just went zipping past in a straight line like that? Do they think this is probable? What might be a more likely shape for this situation? A circle!

What do we know that is special about a circle? How many degrees are in a circle? How many hours are there in a day? Could we figure out some things about where the Sun might be shining in one hour? What about in five hours? Where will the Sun be? On a globe, we could try to guess this place and look on the Internet. (The Thread, *Time Warp*, begins some thoughts on Time Zones.) England is five hours from Eastern Standard Time, and there is a great Internet site for Cambridge, England, where a live camera takes a wide angle shot of the University there every few minutes. This visual proof can be turned around in such a way: Thinking about a circle seems very mathematical and not related to our world very much. However, if we recall that we made a circle from the motion of the Sun in our experience, then it must be said that what can be predicted from a circle can be applied to the apparent motion of the Sun.

Does that circle mean that the Sun is moving around the Earth? Could there be another way of seeing the Sun do what we've just seen it do? Here is the challenge of perspective, and this will be the most difficult of all. Imagine you were born and lived on a spinning carousel. You've never known the ground. What would your view be like? All around you the world would be spinning past, but the things on the carousel would stay in place. How easy it would be to believe that you are standing still and everything else is moving, if you've never been off of the carousel.

Place a bright light source or even a student at the front of the room. Have the students stand such that their left shoulders are pointing to the light source in the same way their shoulders pointed to the Sun. Ask the students to then say where in their vision does the light source lie. Give them a blank piece of paper. They should say or even draw the light at the very left of their view or paper. Just drawing where the light source is in their view might be superior to drawing the room and the light source. The reason for this is, as they are spinning about past the light source, the room is also appearing to spin. Thus, the idea of the light source appearing to move becomes moot, because the entire room will appear to move. This is not what we saw when we watched the Sun all day long. We saw the Sun appear to move past the scenery. So, perhaps saying that they should draw where the light source is instead of what they are seeing will help them develop a better mental model of what is happening.

Ask them to turn counter-clockwise until they are facing the light source. Have them again say or draw where the light is in their field of vision. The view will be that there is a room with a light source in the middle. Then ask them to turn again so that the light source is on their right shoulder. Have them tell you about or draw this final view. This time, the room should appear to be filling their view except for the very right side, where there is a light source. They may want to glue or staple the drawings into their journals later.

Putting the pictures in the order of their movement, does anyone see a pattern? Put the easel and its drawing in the front of the room. Does anyone see a connection? What two types of motion do we now know can cause the pattern we have observed? If the light source were the Sun, what time of day would the first drawing represent? Where is mid-day? What would happen if we spin around past the point where the light source was at our right shoulder? Our backs would be to the light source. Is this what happens at night? Ask the students if everyone on the Earth gets sunlight sometime. This will lead into the question of what kind of spinning shape allows that to happen.

Now the big challenge is to find out what the students think this motion means. The light source "Sun" was always at the front of the room, but on the drawing of our turning, we saw it move across our field of view. Is it possible then that the Earth might be the thing that is moving while the Sun actually stands still?

At some point, it would be good to discuss with your students why you had them face South when they were outside. What would happen if we all had faced the other way? Could we go out and see that? We could explore the school's Daymarks by using the Additional Resource, **Telling Time Without a Clock**. What objects around the school could help us to keep track of time without a watch?

"We don't make mistakes.
We just have learnings."
— Ann Wilson Schaef

"Open your eyes and look at the day.
You'll see things in a different way."
— Christine McVie, *Don't Stop*

"It is an important truth that the ultimate reliance of a human being must be on his own mind."
— William Channing

"By honest I don't mean that you only tell what's true. But you make clear the entire situation. You make clear all the information that is required for somebody else who is intelligent to make up their mind."
—Richard P. Feynman

"Science is not the affirmation of a set of beliefs but a process of inquiry aimed at building a testable body of knowledge constantly open to rejection or confirmation. In science, knowledge is fluid and certainty fleeting. That is at the heart of its limitations. It is also its greatest strength."
—Michael Shermer

You Light Up My Life

Purpose

Next, we want to determine the behavior of sunlight from observations outside and inside the classroom. We will learn about how light travels by using mirrors, prisms, and shadow makers. The National Science Education Standards state that the nature of light is an important topic to be learned in this age group, and the manipulation of tools is crucial. The vocabulary which can be introduced to help talk about our experiences are light, shadow, shade, opaque, transparent, translucent, waves, colors, mirror, rainbow, spectrum, and ray. For a new approach to learning some of these vocabulary words, visit **Word Lore**, an appendix dedicated to exploring the history of words pertaining to this curriculum.

Teacher Background

Light is a very odd thing, but a very special thing. It travels faster than everything else in the Universe. It defines how we measure everything we do, for it travels around, hitting objects and bouncing their images to our eyes. When the images of objects reach us, they allow us to judge the positions of those objects. In that way it is our only good means of determining time. If something moves from one minute to the next, we are most likely to notice this if we can see its image. We can only see its image, if light is bouncing around. Therefore, light can tell us about the world and its changes.

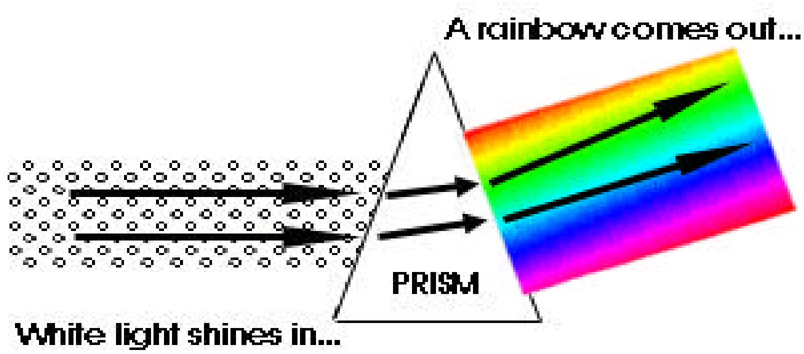
You will need: white paper and masking tape, pencils, crayons, mirrors, prisms, objects of differing transparency, garden hose or spray bottle, flashlights, overhead projector, water and clipboards.

A few sunny days would be good for experiencing this topic. Students will be developing theories about light and need a few chances to test them in the outdoors. Only a few periods of class time are required. (This Thread leads to another Thread about shadows which will take longer to explore fully but supports the same developing understandings.) Gathering materials will take time, as equipment may need to be reserved or ordered.

Our current scientific knowledge suggests that light can act in ways that are wave-like and ways that are particle-like. That light acts as a wave means it bounces off things or interacts with other lights similar to the way that waves in water do. That light acts as a particle means that when it bounces off things, it carries with it energy that can be transferred to the things it hits. An example of this is a sunburn, where sunlight has hit and been absorbed into the skin, burning the cells.

This wave particle thing called light travels in a very <u>straight</u> way, in *rays*, from its source. Anything in the path of the light ray will block the ray to some degree. If the object is very dense and dark, preventing the light from passing beyond it, it is called opaque. Beyond this object, then, on the side farthest from the light source, is what is know as a shadow – where there is an absence of the bright light. You can usually still see things in the shadow because there is other light scattered or bounced about the room or yard hitting that area indirectly. Some transparent objects like glass even let light travel almost completely through them. Objects which may allow only a little light to pass through, like colored plastics, are called translucent. However, the translucent materials often distort the light they let through. This is because light is a strange thing itself.

White light, or the common light from the Sun, is a tight tangle of all visible colors of light. The colors travel together all mixed up in a way that makes our eyes see the combination as bright whiteness. This combination can be untangled if you somehow crack open that tight mixture with a light bending tool. Thick clear things like glass and water are very good at this, but plain glass or water is not enough. They have to be in a shape which makes it tough for the tight light package to get through without breaking apart.



A prism is a piece of glass shaped like a triangular solid, or a triangle stretched upwards to make a three-dimensional shape. The light travels into the triangle from a face of the triangle at a certain angle. Whenever light goes from one medium (air) to another (glass) the different colors of light bend slightly different. The pencil in the glass of water trick is an example of this. Usually, through a flat medium like a pane of glass, the light enters, colors bend by a specific amount, and then bend back into one another going out the other flat side. But the prism, because it is not flat but triangular, doesn't allow the colors to bend back into one another. Instead, it encourages more bending by the angle it has on its other side. So, the white light enters the glass and the colors bend and take different paths through the prism. When they reach the other side, instead of meeting up again with each other passing back into air, each color splits even more from the pack by the same angle again and takes a slightly different path out of the prism. We see the colors spread out in the beam. A spray of water will also make this happen as the little droplet shapes of water work like miniature prisms. You get a misty rainbow in the droplets as the white light package gets ripped open in the spray — exactly as it happens in the sky with real rainbows.

"Imagination is more important than knowledge."
—Albert Einstein

"The tenets of skepticism do no require an advanced degree, as most successful used-car buyers demonstrate. The whole idea of a democratic application of skepticism is that everyone should have the essential tools to effectively and constructively evaluate claims to knowledge. All science asks is to employ the same levels of skepticism we use in buying a used car or in judging the quality of analgesics or beer from their TV commercials."
— Carl Sagan

"The most beautiful thing in the world is, precisely, the conjunction of learning and inspiration. Oh, the passion for research and the joy of discovery!"
— Wanda Landowska

Kindergarten through Second Grade

Developmental Issues

This Thread will focus our experiences of shadows on what light is doing. The students will explore the direction of light and how it always makes a shadow behind an object. We will make it into a game called Sun/Blocker/Shadow which hopefully will root important scientific concepts in a fun game. Five- to eight-year-olds are not very adept at grasping the nature of light. Most undergraduate physics students have difficulty with the concept! However, being comfortable with the way light works is crucial for understanding shadows. Make sure that children understand that when someone says “there is no light” that it’s different from how we talk about dark in everyday language. If a room is slightly darkened but they can still see, it is because there is light available! Providing the concrete experiences offered in this Thread helps children develop a strong base for the complete concepts they will learn when they’re older.

Inquiry Introduction

What are shadows? Where do they come from? How do you make one? What things do you need to make a shadow? Could we make a shadow outside? Inside? In a dark room or at night? Under water?

Inquiry Investigation

Outside, the Sun lights up the world. But what happens when things get in the way of the sunlight? Does everything make a shadow? Where are our shadows? Can I walk up to someone and step on her shadow? Playing a game of shadow tag would be fun here. After the energy is released from play, gather the students around again.

Let's face the Sun and try to find our shadows. Are they in front of us? They are behind us. Let's face our shadows. Where is the Sun? It is behind us now. So, where are shadows going to be when the Sun is over there (point to the left)? Let's face that way. Our shadows would be behind us again, on the other side. So, where do shadows form? On the side of us away from the Sun. Is this true for any light? Can both the Sun and shadow ever be on the same side of us? Could we face the Sun and face our shadows at the same time? Why or why not? What is it about the Sun's light that is not making that happen?

The overhead projector in the classroom gives off a nice light. Turn it on and ask someone to stand in front of it with his eyes covered (otherwise it will hurt). Where is his shadow? He can't see it, but the class can see it behind him. Where should he move to see his own shadow? He turns around and there it is.

What is the Sun? What is the light? Are there things in our classroom which give off light? What are they? Could we think about the sunlight as we do the classroom light? Are there such things as portable lights? Could we use them to think more about light and blockers of light?

What about with flashlights? Could we shine a flashlight on something and make a shadow behind it? In pairs in the classroom, have students shine a flashlight on objects they have in front of them. You could give them wooden shapes and other things. Where are the shadows? Can they change the shape of the shadow or the size?

There seems to be some kind of lining up that has to happen: Sun, blocker of Sun, and the shadow. Could we find a tree and see if it works with a tree? Find a nearby tree and see if the same is true. What about a car or the school? Where is the Sun? Where is the shadow?

Emphasize "Sun/Blocker/Shadow" while pointing to each of these elements in the set-up. Move the flashlight to another spot and show again the different pieces of the Sun/Blocker/Shadow. Let them quiz each other with teams at their own desks. For the youngest grades this may require supervision. You may just want them to play with the flashlights, see if they can tell someone else one special thing they found out about the light and shadows.

A short assessment handout is included that you could use tomorrow to see how many have experienced this fact of light: Light travels in straight lines, so that shadows are directly away from the light source.This handout was created by a first grade teacher as part of the Everyday Classroom Tools curriculum. She had great success with it, and used it repeatedly to reinforce the ideas.

"Mistakes are the portals of discovery."
—James Joyce

Second Grade through Fourth Grade

Developmental Issues

This Thread allows teachers to direct questions towards the nature of light through repeated experiences with it and objects which block it. These students can juggle ideas such as the seen and the unseen. This will help us to get a firm enough grasp of what light is doing that we will be able to predict some things about both it and shadows. Try getting them to notice the world around them, especially things that don't seem to make sense. Encourage them to take the next step in problem solving by coming up with the kinds of questions they would ask to solve the mysteries. Be aware: they will come up with questions that they may not be able to completely answer! Encourage your students to write their questions down in a journal where they could call upon them as they gain further understandings.

Inquiry Introduction

What are shadows? What is shade? Are they the same? What is light? Where does it come from? How is it made? Let's go outside and think more about this. Grab stuff you want to see shadows of and maybe some paper if you want to draw shadows to show people later. Does anybody think there is something which does not make a shadow? Bring it along.

Inquiry Investigation

Outside, find a place where there is space to spread out clipboards and people without overlapping shadows. It may be better to do this closer to mid-day when the shadows are shorter. Have everyone place their test objects on the paper. What do we see? Which objects make really good shadows? Which make weirdly colored shadows? Why might this be so?

In all of this, where is the Sun? Look again at the shadows. Which way do they point in relation to the Sun? Is there anything we could do to change that? Trace the shadow there right now. Then try to find some way to make the shadow look different on the paper. Some will move the object, some will move their position on the ground, others will twist their paper a bit. Draw the shadow again. Whose shadow looks different? Why? What happens when you move the object itself? How did the shadow change? Is it pointing in a different direction? Where is the Sun? What about when you move to a different place? Where and how did you move? How might that have affected the way your shadow looks? Where is the Sun? What about those of you who twisted the paper? Where is your new shadow? Is it still pointing away from the Sun? But where is it on the paper? The paper moved and not the Sun, right?

Why are shadows always pointing away from the Sun? How is light working to do that? How does the Sun know the wooden block is there? Light is somehow hitting the block and making that shadow. What is that area behind the block and away from the Sun? Is there light in there? Not as much as there is around it. So, when light hit the block, did it go through the block? A shadow must be the area behind an object facing the Sun which can get no direct light.

Why is it cooler in the shade? Is the Sun warm? What happens in the shade? It is not getting as much light and so is not as warm. Cool. Exactly.

"Children and scientists share an outlook on life. 'If I do this, what will happen?' is both the motto of the child at play and the defining refrain of the physical scientist...The unfamiliar and the strange—these are the domain of all children and scientists."

—James Gleick

"All men by nature desire to know."

— Aristotle

Fourth Grade through Sixth Grade

Developmental Issues

This Thread offers fourth through sixth grades the opportunity to tackle the theory of light through different and more serious experiences outdoors. They are ready to ask and be asked some deep questions which will hopefully open their analytical minds to the possibilities of even deeper questions for real understanding. Providing them with tools and time is all we need for them to create a fairly good theory of the nature of light. Even if they don't come up with the same theory that scientists currently hold, they are learning about *theory generation*, how we come up with the best explanations that we can until we learn something new to help us generate a better explanation.

Inquiry Introduction

Why can we see the world around us? What outside conditions cause us to see worse or better? Students will mention the weather and amount of light. Why does the weather affect our view? It will become obvious that the weather can block light, such as on a cloudy or rainy day. So, really, the only factor is light. What is this light stuff? Where does it come from? Does it only come from the Sun? What other things give off light? Fire and friction are good examples, friction being what causes light bulb filaments to glow. (This may be new to this age group. If so, it would be useful to have all of the class rub their hands together and tell you what happens to the temperature. Can they think of other familiar objects that produce heat in this way?) Phosphorescence is another way of making light, but a very confusing way at that. How does that little sky spot of the Sun make the whole town light up? What is light doing? How might we figure out more about it?

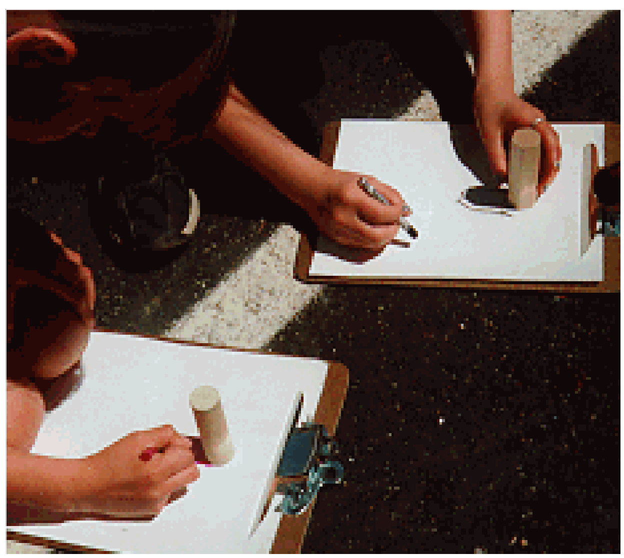
Have the class make strategies for learning more about the Sun. Brainstorm about ways to test theories. For example, one hypothesis might be that the sunlight glows in the air. How could we test that? Is there a way? One way might be to get a clear container of air and shine a light in it, then turn the lights off. If the air is still glowing inside, that could be interpreted as evidence for the theory. What other thoughts might they have about how light works? Now might be good time to talk about reflection.

Inquiry Investigation

Bring outside (on flat ground or pavement with paper) all of the things they might need to discover properties of light. We suggest you bring mirrors, objects of varying opacity, closed boxes, flashlights, paper, tape, etc. (Please note: It is an unfortunate fact that children outside with mirrors will try to aim the bright sunlight into the faces of others. You should consider using mirrors indoors with flashlights, which are weaker, or mentioning that mirrors will be taken away if students cannot behave properly with them.) Encourage your class to build devices for trapping or analyzing light.

Why are shadows on only one side of an object outside? Do they ever move? Why or why not? Most will say that the Sun is shining and hitting the object on one side of it, and the shadow forms because the light can't get through to the other side of the object, so there's no light there. Trace the shadow on the paper. Twist the paper. Where is the shadow on the paper? Where is the Sun? Is the shadow still pointing away from the Sun? But where is it on the paper? Did the Sun move? But the shadow changed because what we were measuring it on moved. Keep this in mind when we do the Sun stick measurements in *This is a Stickup!*

Why can you still see the pavement in that shadow? Surely there must be some light coming from somewhere? What is happening? What happened to the light that hit the block? Did it get sucked into the block? Did it bounce off the block? How can light bounce? What other things can bounce like that? Many will say playground balls or something like that. Is light made of little balls of bright stuff? If so, what could we do to test that? Here is where the mirrors come in.



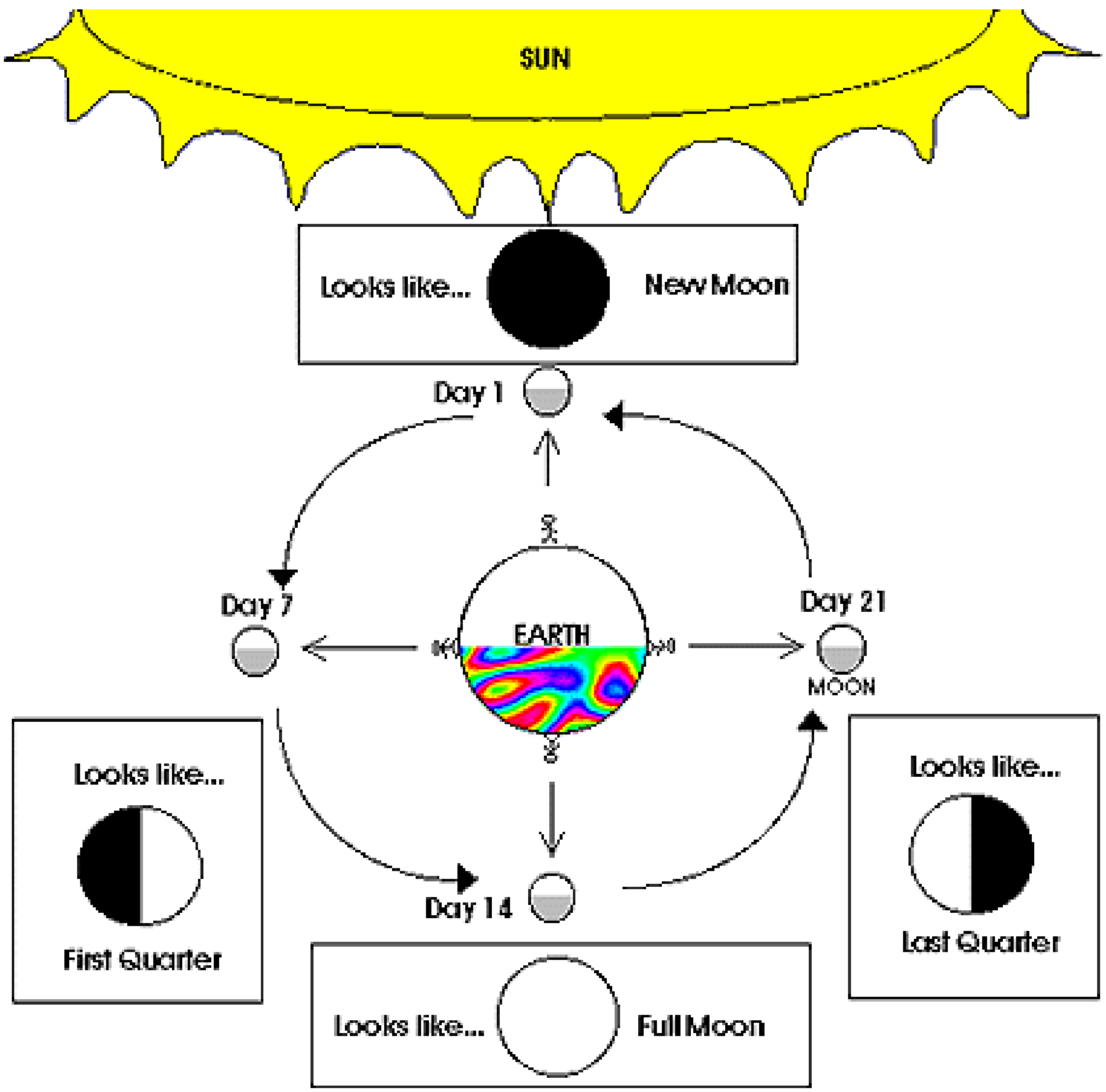
It is hard to see the light bouncing from the block, but easy to detect light which is being bounced from a mirror. Can we bounce light around the yard? How far can we get before it is difficult to catch the beam of light? If light can bounce so well off mirrors, might it not bounce around off other things, but not as well? Probably. That is why it still gets around the whole yard, even the pavement inside a shadow, when the Sun is in one place in the sky. This is why it gets bright out in the morning even before the Sun rises. And that it is still light just after the Sun sets. Light indeed travels in very straight lines, but light itself can bounce though it still travels in straight lines from object to object.

Phases of the Moon

Phases of the Moon are not caused by the Earth's shadow. They are due to a change in our viewing perspective as the Moon orbits around us as it is lit by the Sun. We are looking down at the Earth, Moon, and Sun in the diagram below. The Sun lights up half of the Earth and Moon, drawn here as the white side, just the same way a flashlight lights up one half of a ball. The Earth spins in the light, so that the entire Earth gets to be lit at some point each day. Even though the Moon is always half-lit like the Earth is, sometimes we on the Earth see only a tiny bit lit, other times completely lit, depending on where the Moon is in its orbit around the Earth.

The Moon's orbit is a little bit tilted, so sunlight shining around the Earth reaches the Moon when the Moon's tilt puts it above or below the plane of the Earth's orbit. Otherwise, the Moon would be eclipsed every month when it moved into the Earth's shadow! You can demonstrate phases by turning a ball around in a circle above your head as you stand in the beam of an overhead projector.

A question to think about is can you see the Moon in the daytime? Look at Day 7. What time of day is it for our little guy? Is he in light? Could he see the Moon in the light? Where would the Moon be in the sky?



Me and My Shadow

Purpose

In this Thread, we will become familiar with the orientation of shadows, their size in relation to the object casting them, and how the alignment of the Sun, the object, and the shadow tells us much about how shadows work. The National Science Education Standards stress that geometry and light should be integrated into curricula as tools for learning about three dimensional objects. Vocabulary words which can be used to help talk about our experiences are alignment, casting, angle, and light source.

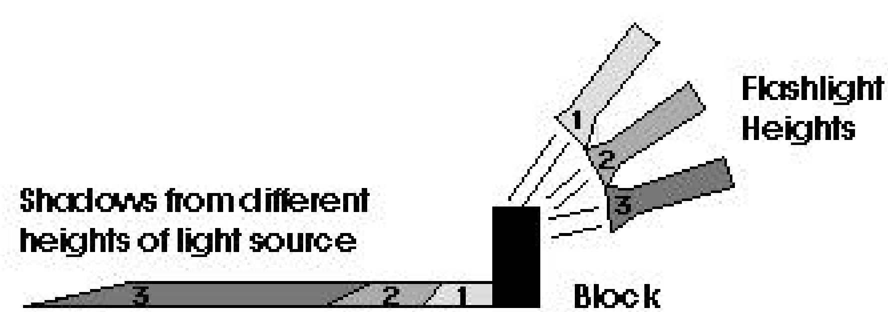
Teacher Background

> You will need: enough pebbles, coins, marbles or counting blocks for the entire class, a box of chalk, chalk/wipe board and markers, overhead projector or lamp.
>
> This requires one class session outside in the sunlight. Another class session or two inside is enough time to really think about our outdoor experiences. Materials gathering is quite minimal.

The height of a tilted light source (in other words, the angle between the light source and the ground) and the size of the object it is illuminating determine the length of the shadow that the object casts. The object blocks the light coming from the source so that nothing behind the object gets any direct light. The length of the shadow is a result of how high above or below the top of the object the light source is. Imagine if the light source were directly above the top of the object. Would there be a shadow? No, not one that would be visible around the object. Twist the light source a little down from the top, and a shadow appears behind the object, but is very short. This is because as the light source moves down, the shadow is being created by the small area of the object blocking the light. Imagine straight lines coming down from the light and hitting the object. The higher the light, the less light lines get blocked by the object and hence the less shadow. Thus, the lower the light source is aimed at the object, the more the object blocks the lines, or rays, of light.

The key to understanding shadows is to realize that the light source and object must be lined up in order to make a shadow appear. In fact, if the object is placed anywhere along that line, it will produce a shadow of the same length. It is only when you change the orientation of light that the shadow changes its length.

Shadow basics make good sense in this order: light hits an object and casts a shadow behind the object. But experiencing the connection of light/object/shadow under different circumstances is good for rooting our experiences more firmly. This Thread will ask students to predict where to put an object to cast a shadow along a certain line towards a target area, i.e. experiencing *backwards*, in a sense, the circumstances under which they make a shadow .



> "Inquiry is central to science learning. When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills."
>
> —National Science Education Standards

Kindergarten through Second Grade

Developmental Issues

This Thread invites Kindergartners through second graders to continue to think about light and shadow while using their bodies to make observations. This roots our experiences by relating them to ourselves, which is fitting for this age group. It engages students in manipulating objects with a focus in mind as well as exercising balance and movement skills which are good for this age group. Teachers of second graders should consider using the grade 2-4 version of this Thread.

Inquiry Introduction

Remember the game Sun/Blocker/Shadow? Why does it work? What other game could we devise to play with the way light works? Everyone grab a marble or cube. (Don't call the cubes "blocks" or it will confuse the game.)

Inquiry Investigation

Together, let's go outside and find a place to spread out on an area of asphalt or concrete, etc. Where are our shadows? Can everyone find his or her own shadow? Where is it? Is everyone's shadow visible? Can the teacher come and step on someone's shadow? Does it hurt to step on a shadow? How far away from the person is the teacher who is stepping on the shadow? Is it hard to reach the person from where the teacher is standing? Why are shadows so far away from their makers?

Play Shadow Tag again, this time with some questions afterward. Was it hard to play this game? We had to be careful to watch our shadows and the person who was "It" very carefully. When was it hardest to be careful: when running towards the Sun or away from it? Why? How are shadows made, then?

Now it is time to reverse our thinking. Everyone, drop your cube somewhere. Where is your shadow? Can you move your shadow so that the shadow of your hand can cover the little cube on the ground? This will at first seem quite difficult, but soon they will begin to cry out that they have done it. Helping is definitely OK.

How did you knew where to put your fingers? They will begin to vocalize in their own ways an important fact: that the sunlight is in straight lines to their hands and they need only line themselves up with the Sun and the cube to cast a shadow on it. In this way, they have figured out that one can determine the position of the light source from the angle of a shadow they can cast.

Can anyone think of a way to play this game in the classroom?

> "Somewhere, something incredible is waiting to be known."
>
> —Carl Sagan

> "A vision's just a vision if it's only in your head. If no one gets to hear it, it's as good as dead. It has to come to life!"
>
> —Stephen Sondheim, *Sunday in the Park with George*

> "Individuals internalize their experience in a way which is at least partially their own; they construct their own meanings. These personal 'ideas' influence the manner in which information is acquired. This personal manner of approaching phenomenon is also found in the way in which scientific knowledge is generated. Most philosophers of science accept that hypotheses or theories do not represent so-called 'objective' data but that they are constructions or products of the human imagination. In this way of thinking, observations of events are influenced by the theoretical frameworks of the observer. The observations children make and their interpretations of them are also influenced by their ideas and expectations."
>
> —Rosalind Driver, *Children's Ideas in Science*

Second Grade through Fourth Grade

Developmental Issues

This Thread will examine the orientation of the Sun, ourselves, and shadows from the reverse way around. It will seem like a tricky game, but once the idea of the linear nature of light travel is experienced, we can talk more about light in the next Thread. To do so, again we will exploit this age group's fascination with mystery, team learning, and the ability to string two or more variables together into a model. Second grade teachers should consider choosing this version of the Thread over the version intended for younger (K-2) students.

Inquiry Introduction

What has to happen before we can see a shadow of ourselves? There must be light. There is light and us, but there is something else we need to actually see the shadow. We need something for the shadow to land on. So, three things are required for shadows: a light, an object, and a surface. Is there any guideline for where the shadow should land when we are standing in the light? Does it matter where we put the light? What about in outer space?

Inquiry Investigation

Everyone should grab one small shiny object like a new penny or an interlocking math cube, a pink eraser or a marble. Let's go outside. Find an asphalt or concrete area with a lot of space, so that the entire class can spread out and be in sunlight. Is there enough room for their shadows? You might consider timing this for between 11 a.m. and 1 p.m., when the shadows are shorter but not so short as to make this impossible.

Everyone should spread out enough that they can twirl in place and not hit anyone. Next, everyone should drop their shiny object somewhere about 4-5 feet from them in any direction. Now find your own shadows and stick your arms out. Make an OK sign with your fingers, so that your shadows show a little ring or circle for your hands. Can you, without squatting, move your shadow ring so that it encircles the shiny object on the ground?

They will mock this as easy at first, until they find it is very difficult. There is some kind of trick to doing this, and it will be fun watching them catch on. What has to happen before the shadow can line up with the object? What else is needed to make a shadow besides the surface and the thing making the shadow? The Sun. See how many can incorporate this into their struggle. There has to be an alignment of the three crucial items needed in making a shadow happen.

Soon, (it takes about 3-4 minutes), they will begin crying out that they have figured it out, one by one. Ask them what they did, and they will try to explain they made things line up or they looked back to where the Sun was. It is the lining up of these objects which is so crucial to learning about how light and shadows work. If someone has managed to ring the object by luck, ask about the positions of the things needed to make a shadow. Is there any pattern? Can we shuffle from side to side and still make the shadow happen on the object? Can we shuffle forward and backward and still make the shadow happen on the object? How? Where must the Sun be in order for this to work? Directly behind our hand. Where must the object be in order for this to work? Directly in front of our hand.

Where is the Sun? Where is our shadow? Have them face the Sun. Where is our shadow? Turn to the left. Where is the Sun? Where is our shadow? Is there a pattern here? What if the Sun were over there (point to the left)? Where would our shadows be? What is true then about shadows and the Sun? Shadows point away from the Sun. Do shadows point away from a lamp as well? We can play with this back in the classroom.

They will want to play more with this trick once they all have caught on. You can ask them if they can get two people to circle the object at once from different positions. Break into teams of shadow makers. Can anyone make other shapes with your body to circle the object? Does everyone have to stand at the same distance from the object to ring it? How many people can you line up who are casting a shadow around the object but are standing apart from each other?

Back in the classroom, let's pool what we've seen. We saw that we had to line our hand up with the Sun to make a shadow, but we also had to line that shadow up with the shiny object. We had to move our entire bodies so that the Sun was at our back to get the OK sign over the object. We found that we could also move towards it and away from it and still keep the OK ring around the object by moving our hand only slightly.

Draw on the board a Sun, a person with her hand out, and the object, but do not line them up in the proper was for the person’s shadow to hit the object. Will this person’s shadow hit the object? Why or why not? Students should gather in the same teams that they were in outside. They should think about the question on the board and then come up with an answer. Ask the teams in turn what they think. They will hopefully mostly say no, this cannot happen. Why not? They will talk about things not being lined up. You could prod them more by asking if they mean you can't draw a straight line which connects them all. Draw a line that connects the three items, first asking what the order is. Sun, object, shadow....It should be a terrible angle whose sides do not make a 180° angle. Where would I need to put the person to make the line straight? Teams can confer and answer you in rotation. Have them come up to the board and place an X where they think the person's hand should be. Different colored chalk would work well for different teams, otherwise numbers will suffice. Does everyone agree? If not, more examples like this could be done.

Is this what we experienced outside? We had to line up everything to make it work! Why? What must be true about sunlight or any other light source? It travels in straight lines.

"When long shadows fall
And dwarf the trees at evening
When white winter light
Burnishes the trees,
Then I will bring you a coat
Of soft lamb's wool,
To keep your back from
The keen northern wind."

—Maddy Prior, *Long Shadows*

"People always say that it's the simple ideas that are truly the ingenious ones, because millions of others have already overlooked them. Take off the blinders and never think that an idea is crazy. If one idea doesn't work, don't get discouraged. Get back up and start again. If people call your idea crazy, it's probably because they don't understand it, or because they're jealous that they didn't think of it first."

—Karen Schlangen

Fourth Grade through Sixth Grade

Developmental Issues

For this age group, this Thread involves a quick investigation outside to exercise our powers of perception. Although this is probably a little easy for them, it is still a good idea for them to be familiar with every aspect of the shadow making process.

Inquiry Introduction

What makes a shadow? Most will know that shadows are caused by the Sun or other light hitting an object and blocking the path of light behind the object. This is easy, right? You can make a shadow fairly easily and determine where the light source is from just looking carefully at a shadow. But can you aim a shadow at an object? Huh?

Inquiry Investigation

Everyone should grab one small shiny object like a new penny, interlocking math cube, a pink eraser or a marble. Let's go outside. Find an area of asphalt or concrete with a lot of space, enough that the entire class can spread out and be bathed in sunlight. Is there enough room for their shadows? (You might consider timing this for 11 a.m. or 1 p.m., when the shadows are shorter.)

Everyone should spread out enough that they can twirl in place and not hit anyone. Next, everyone should drop their shiny object somewhere about 4-5 feet from them in any direction.Now find your own shadows. Make an OK sign with your fingers, so that your shadows show a little ring or circle for your hands. Can you, without squatting, move your shadow ring so that it encircles the shiny object on the ground?

They will mock this as easy at first, until they find it is difficult. There is a trick to doing this, and it will be fun watching them catch on. What has to happen before the shadow can line up with the object? What else is needed to make a shadow besides the surface (shiny object) and the thing making the shadow? The Sun. See how many can incorporate this into their struggle. There has to be an alignment of the three crucial items needed in making a shadow happen.

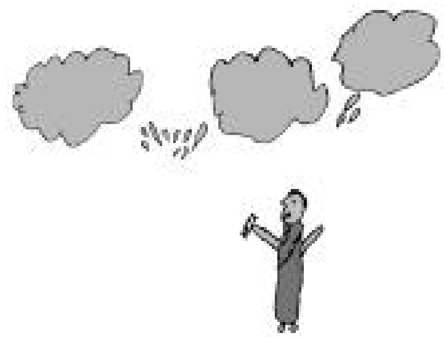
Soon, (it takes about 1-2 minutes), they will begin calling out that they have figured it out, one by one. Ask them what they did, and they will try to explain they made things line up or they looked back to where the Sun was. It is the lining up of these objects which is so crucial to learning about how light and shadows work. If someone has managed to ring the object by luck, ask about the positions of the things needed to make a shadow. Is there any pattern? Can we shuffle from side to side and still make the shadow happen on the object? Can we shuffle forward and backward and still make the shadow happen on the object? How? Where must the Sun be in order for this to work? Directly behind our hand. Where must the object be in order for this to work? Directly in front of our hand.

> Today, all sciences are based on actual experiments, although much of the application of scientific facts is still a matter of theory. The fact, however, that we strongly believe in a theory is no proof of it, and this should always be kept in mind.
>
> — Pulvermacher and Vosburgh, *The World About Us*

Pourquoi Tales

Pourquoi tales are ancient stories which explain why something has happened. Here are a few modern Pourquoi tales written by third graders whose teacher integrated the ancient tales into her Threads of Inquiry curriculum.

•Why we have Clouds in the Sky



Once upon a time, about six million years ago, there was a boy, six years old, named Duran. He lived in India. One day, he was digging in his yard when he felt something cold and wet. "A stream!" he said. Then Duran had a mischievous idea. "Oh, Dulran," he said in a sing-song voice. Dulran, Duran's identical twin brother, came outside. "What do you want?" asked Dulran. Duran told Dulran to fetch his pea shooter. Dulran got it for Duran. Duran sucked up the water from the stream and shot it out of the pea shooter, aiming straight for Dulran. Dulran ducked, so the water went up into the sky. That is why we now have clouds in the sky.

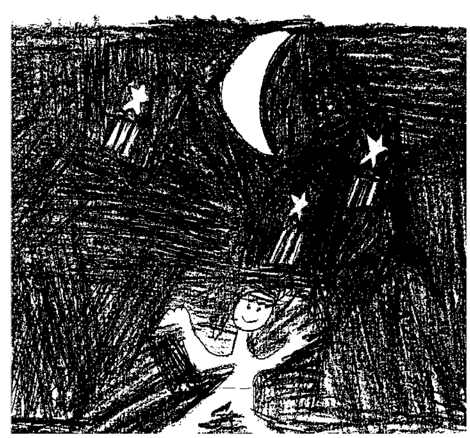
•Why the Clouds Are in the Sky

Once there was a bunch of kids who were in camp. There were around a camp fire. They were roasting marshmallows on the camp fire. They were having fun, but all of a sudden the fire blew up. And the marshmallows blew up into the sky. And that is why we have clouds in the sky.

•How the Moon Got in the Sky

There once was a lazy moon. He lay about and did no work. So the people tried to put him in the sky. They got a helicopter and got the lazy moon from the tree. They put him on a platform in the sky. There he stayed for ever and ever until the moon comes down and starts all over again. Now the lazy moon has to work all the time lighting up the night sky. The best punishment. OY!

•How the Moon and the Stars Were Made



Long ago there was a little boy called Flying Eagle who worked a lot but he lived in the small little wigwam. When he was digging for water he found something shiny. It was gold. He dug more. He found more and more. When he was eating a banana, he thought of making bananas out of gold. He made a golden banana and threw the golden banana up and up. That is how the moon was made. But some gold was left, so he threw the gold up to the sky and that is how the stars were made.

Guess My Shape

Purpose

Understanding how light hits things of different shape and form necessitates an understanding of shape and form. Becoming familiar with the shapes around us and having a language to talk about them helps us when we describe other things which are happening in our world. The National Science Education Standards suggest introducing the rectangular solids in elementary school and the manipulation of shapes and perspectives throughout the school year. Older students will benefit from the application of math skills to shape and structure. Vocabulary words which can be introduced to help us talk about our experiences are shapes, edges, sides, cylinder, sphere, triangular solid, rectangular solid, cone, pyramid, and cube.

Teacher Background

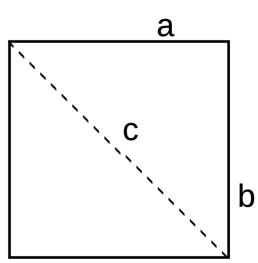
You will need: buckets of wooden solids, overhead projector, flashlights, paper, pencils. K-2 will need paper plates, ball, clay or a clay substitute and drawing materials. 2-4 will need a cardboard shield constructed ahead of time, and 4-6 needs pipe cleaners and tape.

Depending upon the level of your students, you may need more or less time to talk about shapes. However, a few class periods is probably sufficient, although referring to shapes throughout the year is a fine way of keeping the topic alive. The amount of time needed to collect materials is minimal, unless you need to order the wooden solids.

There are several basic shapes in our world which show up time and again. We call these the regular solids because their construction is from simple shapes like circles, triangles, and rectangles. To make one of these shapes is to imagine a triangle, say, sitting flat on the table as if cut out from a piece of paper. Flat as it is, it is nearly two-dimensional. What if you could give it height? Imagine being able to grab hold of the three sides and stretch them upwards. From above, it would still look like a triangle, but from the sides, it would look like a building with three sides. This is called a triangular solid. The same technique is used to make a cube or cylinder. These shapes are often called “prisms”, but are quite unlike rainbow prisms, so we should not refer to these shapes as such. Instead, they are rectangular solids, because a shadow cast from the long side is always a rectangle.

To make something like a pyramid or cone, you must imagine a similar procedure. Instead of stretching the sides up to make the solid, you imagine that you pull them up and together to a point at the top. Or imagine you cut paper into smaller and smaller versions of the flat shape and place them on top of one another until you have cut out a single point, which is the very top. So, a four-sided pyramid is a square onto which is placed a smaller square and so on. The sides slope as the size of the square shrinks. The same with a cone, but you start with a circle as the flat shape and build up on that.

Pulling shapes through a third dimension means that light shining on these shapes can fool the eye when looking at their shadows. The shadow cast by a light shining on the face of a triangular solid will produce a rectangle. If you knocked the triangular solid on to one of its long sides and cast a shadow from a light shining at one of its ends, you would see a triangle. This is the nature of the regular solids. They have the capacity to fool you when seen only in shadow.



$c^2 = a^2 + b^2$

Thinking about the way light hits objects is a good way of thinking about the geometry of these solids. In math, we say that the length of the diagonal cut across the face of a square, let’s call it “c”, is equal to the square root of the squared lengths of the two sides, a and b. This means that the diagonal is longer than the sides by a little bit. You can find this out yourself with shadows cast on a rectangular solid. If the light is aimed at a side of the solid, the shadow will be a certain width. However, if the solid is turned slightly so that the light is aimed at a corner, the shape of the shadow will still be slightly wider than before. This is the nature of the projection effect of shadows cast from different angles of a rectangular solid.

The ability to roll is something only the circle-based solids have. We cannot talk about corners with these shapes, as there are none. There are edges and surfaces, but no corners. A corner is a point where in flat space, two sides would meet. In three-dimensional space, it is where three or more edges meet. An edge is a meeting of two sides, or faces, like the spine of a book or the sharp lines down the cube.

"For having lived long, I have experienced many instances of being obliged, by better information or fuller consideration, to change opinions, even on important subjects, which I once thought right but found to be otherwise."

—Benjamin Franklin

Kindergarten through Second Grade

Developmental Issues

For Kindergarten through second grade, this Thread focuses on manipulating shapes and sorting objects. This is a great exercise for this age group. They are quite capable of sorting by size and are learning about classification. Geometrical classification by shadow casting may be a bit too complex for them, because children at this age tend to find hierarchical categories confusing. In part because, they tend to assume that categories are mutually exclusive! Superordinate categories create the most difficulty.

Inquiry Introduction

Let's play with shapes in the light to get a feel for shadows of shapes.What is a cube? Which of these shapes are round in some way? How could you sort these objects into groups? What are some things about these shapes that make them different from other shapes? What names would you give for these shapes?

Inquiry Investigation

A tabletop full of geometric solids and their flat counterparts is a good visual. If there are enough shapes, one set at each group table would be great. How could we sort this group? Students may find links between the triangle and the pyramid or the cone and the pyramid. Can anyone explain why they made the grouping that they did? What does the group look like when placed on the overhead projector? Is there a way of making a group on the overhead projector whose shadows look alike?

How do some shapes when put together look like other shapes? What kinds of pictures can we make from just moving these shapes around? Where have we seen these shapes in the world? Why aren't tires made from cubes? Why aren't ice cream cones made from box shapes?

What is the shape of our world? They will likely say round. What is round? Have them draw the world as seen from a rocket in space. What colors did you use? What sizes would you see? How many of you put more planets in or made a crescent moon? Have them talk to you and the class about their drawing. Most every child will have drawn a circle Earth.

Hold up a paper plate and a ball. Which one of these is round? They will say both are, but the world is like the ball. How do we know that? Could you walk all around it? Could you sail around it? Could you dig through it? What if the world were like the plate? Could you travel around it, or might you fall off the edge?

Have them make clay or clay substitute planet Earths. What kinds of things are on the Earth? Water, land, ice, clouds, air? What does light look like when it hits the world shape? Make a mark for where you are on your world. Face your mark towards the light of the projector. What time of the day is it for you? Is there someone on your world having night? Where? Make your mark on your world have night. Are there other people on your world having day while you have night? How much of your world is having night with you? Is this how it works on the big world?

> "If you try to impose a rigid discipline while teaching a child or a chimp you are working against the boundless curiosity and need for relaxed play that make learning possible in the first place... learning cannot be controlled; it is out of control by design. Learning emerges spontaneously, it proceeds in an individualistic and unpredictable way, and it achieves its goal in its own good time. Once triggered, learning will not stop--unless it is hijacked by conditioning."
>
> —Roger Fouts

> "Great inventors and discoverers seem to have made their discoveries and inventions as it were by the way, in the course of their everyday life."
>
> —Elizabeth Rundle Charles

> "Our species needs, and deserves, a citizenry with minds wide awake and a basic understanding of how the world works."
>
> —Carl Sagan

Second Grade through Fourth Grade

Developmental Issues

This age group can think about multiple variables and is capable of imagining other viewpoints and places. For this age level the Thread is focused on speculating about projection of a shape before jumping right into shadow images of them. It engages students in thinking about the function of edges, sides, and corners.

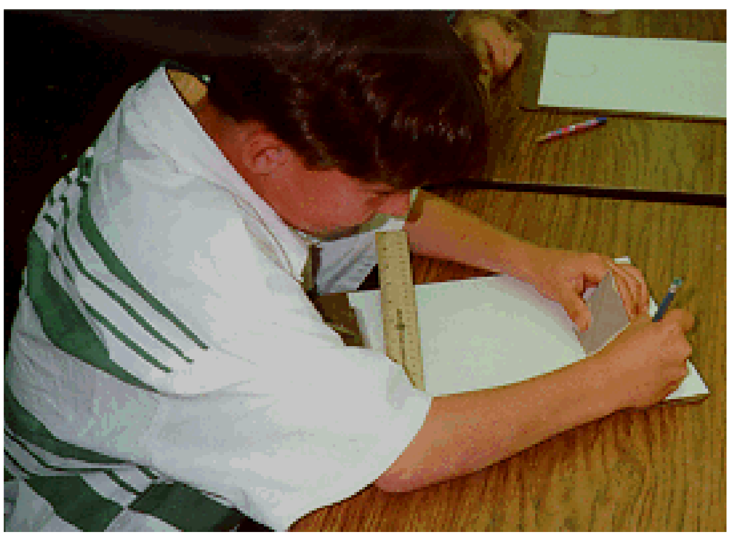
Inquiry Introduction

What is a three-sided shape? What is a four sided shape? what is the shape of our world?

Gather the sets of rectangular solids into groups and give them out to teams of students at desks. Have them list the different groups of shapes in their pile: which have sharp edges, which can roll around, which have four sides, five sides, etc. They will find many different ways of classifying their shapes. Have them talk to the class about their shapes and the groups they made from them.

Inquiry Investigation

What do shadows of these shapes look like? What if the shapes were not sitting on the paper and were instead floating in space? What would the shape of the shadow of our world look like? It is in space with a big light source shining on it. Shouldn't the Earth have a big shadow behind it?



Block the overhead projector from the class with a cardboard shield so that they can't see what sits on the projector but can see the projection. Put a shape on the table of the projector and have them try to guess the shape that is sitting there from the projection. It may be hard to figure it out because of how sometime two very different shapes can make similar shadows. Ask them which shape this could be and why. For example, a triangular solid sitting lengthwise on the projector table will look like a rectangle. Ask them what they could do to be really sure of what the shape was, besides moving the blocking screen you have constructed? They will hopefully say to rotate the object or turn it over on the projector table. A triangle will show up, and then it is obvious. Lift the shape so everyone sees it and go to the next.

Play around with these shapes, asking if this is the shape of the world. Keep the sphere last. When you put the sphere on, ask them which shape this is. It is the sphere or ball shape. This is the shape of the world, so what does that mean about its shadow as cast behind it through space? Let's be sure. No matter how you rotate the sphere, it always casts a circular shadow. So, if the Earth's shadow were to hit anything, it would be a circle-shape, and that would let us know we were right about the shape of the world. Are there any other shapes that can make a circle shadow? Put a quarter coin or other larger circle shape on the projector table. You see a circle. How can you be sure? You will have to turn it or rotate it. It is then a thin line.

Does the world ever turn around? What would that mean about its shadow? If it were a flat circle, then its shadow will change from a circle to a line. But if it is a sphere, its shadow should always be a circle. Is there anything in space the Earth's shadow would hit? Is there anything that is somewhere close by us in space? The Moon is the closest object to the Earth. Does it ever get in line with the Earth's shadow? (Please note that many models of the Solar System show the planets' orbits all in line with the Earth's as well as cramming all of the planets very close together. These models have confused and misinformed students and teachers alike for decades.)

If there is a lunar eclipse soon, this obviously would be a great introduction to it. Otherwise, locate pictures of past eclipses. What is the shadow's edge shape? It is definitely circular. What does that mean about the shape of our world? Cool. We have provided supplementary material about solar eclipses as well at the end of this Thread, to demonstrate how the straight line, Sun/Blocker/Shadow, works even in space.

> "Ignorance more frequently begets confidence than does knowledge; it is those who know little, and not those who know much, who so positively assert that this or that problem will never be solved by science."
>
> —Charles Darwin, *The Descent of Man*

Fourth Grade through Sixth Grade

Developmental Issues

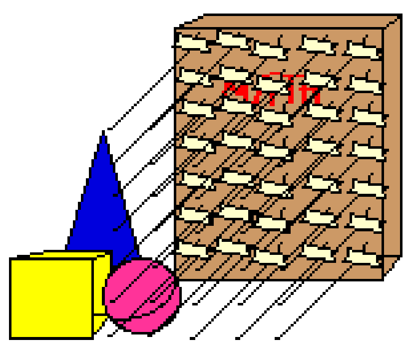
We will approach this Thread from the geometry of the light/solids interaction. Projection from two dimensions to three or vice versa is possible with this age group, as is trying to relate this to how light "sees" objects in the third dimension. Manipulation of rulers and pencils and working carefully in groups is easier for this age group as well.

Inquiry Introduction

What are shapes? What makes a shape three-dimensional? Why are shadows the outlines of objects? Why do they seem to sometimes not quite look like the object they are hitting? When light travels past an object, it catches the edges of the object. Is there a way we could make "shadows" just by thinking about the outlines of objects?

Inquiry Investigation

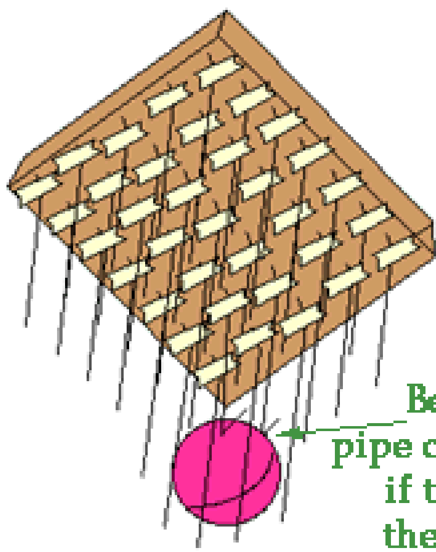
Draw a square on the board. How can I make this square look like it is three-dimensional? Hopefully they will say you need to give it some kind of depth. Extend its sides outward and then connect them again in a square until you have a cube. What is this shape called? Hold up a wooden cube block and orient it to the drawing. Draw a triangle and repeat the depth idea until there is a triangular solid. Hold up a wooden triangular solid and orient it to the drawing. What would these shapes look like if we were looking at them from here, in front of a face of the cube or triangular solid? Many should be able to see it would just be a square or triangle.



Encourage everyone to try making three dimensional shapes on paper in front of them. How does light see three dimensional shapes? Can we even try to model that?

Have teams of three or more people pick a large and solid shape from a selection of shapes. Give these instructions to the students. Place the blocks on big sheets of paper and trace their position. (Note: This can lead into or follow a multiplication exercise.) Take 35 pipe cleaners, tape each one by an end to the front of a covered textbook, forming a neat 5 x 7 grid pattern. An array of pipe cleaners should now be sticking straight out from the textbook, making the book look like a big hairbrush. Have one student aim the pipe cleaners on the book from some angle above and to the side of the block. They may want to measure the height of the book above the desk top.

What is this representing? What are the pipe cleaners supposed to be? Have them move the book along in the direction the pipe cleaners point until they hit the paper and the block. Any pipe cleaners that hit the block can be bent back out of the way, while the other pipe cleaners reach past the block to the paper. Tape the pipe cleaner ends to the paper or block where they hit. Move around the class to make sure every team and/or student understands the procedure. One student should carefully trace and darken the area where there are no pipe cleaners touching the paper. What is this area called? What is the shape? Teams with triangular solids, for example, will find that their pipe cleaner shadows are very rectangular. Why is this?



Can any of the groups explain what they are seeing happening here? Urge them to think about what the shape "looks like" to light. Can you close one eye and peer at the shapes and see the projection effect? If light really does travel in straight lines, then these shadows are correct. How could we be sure? Get a bright portable lamp and place it at the same height the book was. Don't turn it on yet. Slide the lamp in front of the block, still at the same height as the book. What shadow did it make? Is it the same shape of shadow which the pipe cleaners made?

What if the light were coming from directly on top of the block? Move the lamp above it. They will see there is little to no shadow. Where is the shadow? Does anyone lift the block to see the shadow below? Remember, to have a shadow, you need a light, a blocker, and something to cast the shadow on.

What is the shape of the world? Hold up a sphere. What kind of shadow would this make? When light rays hit it, what shape do they make? Students should be able to see they make a circular shadow. Move the ball to a different orientation, which won't look very different. Now what kind of shadow will be made? The same.

What about in space? Is there anything the shadows can land on? Does the Earth have a shadow? Is there a light, the Sun? Is there a blocker, the Earth? Where could the shadow fall? What else is out there? Many will suggest the Moon or other planets. So, the Earth makes a circular shadow. If this is true, the world would make a circular shadow on the Moon sometimes.

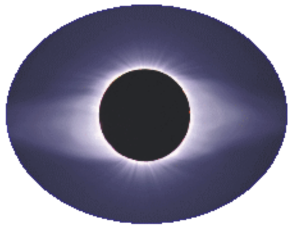
If there is a lunar eclipse happening soon, this would be a great introduction to eclipses. Otherwise, locate eclipse photographs to show them some pictures of a real eclipse. What is the shape? It is definitely circular. How long does an eclipse take? Hours. What does the Earth do in a few hours of time? It spins. So, if the Earth were a flat circle that spins, would it always cast a round shadow during the eclipse. What does that mean about the shape of our world? Cool.

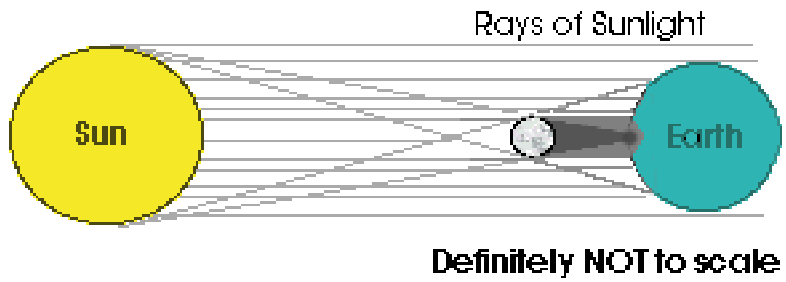
There is a diagram included showing how the eclipses of the Sun occur. It is important to know that theSun/Blocker/Shadow rule works even with objects such as the Sun, Moon, and the Earth. This is why seeing a total solar eclipse usually requires traveling to some other place: you have to be on the exact place on the Earth where the shadow lands along the Sun/Moon/Earth line!

> "My mother made me a scientist without ever intending it. Every other Jewish mother in Brooklyn would ask her child after school: 'So? Did you learn anything today?' But not my mother. She always asked me a different question. 'Izzy,' she would say, 'did you ask a good question today?' That difference--asking good questions--made me become a scientist!"
>
> —Isidor I. Rabi

> "There are many hypotheses in science which are wrong. That's perfectly all right; they're the aperture to finding out what's right. Science is a self-correcting process. To be accepted, new ideas must survive the most rigorous standards of evidence and scrutiny."
>
> —Carl Sagan

Solar Eclipses



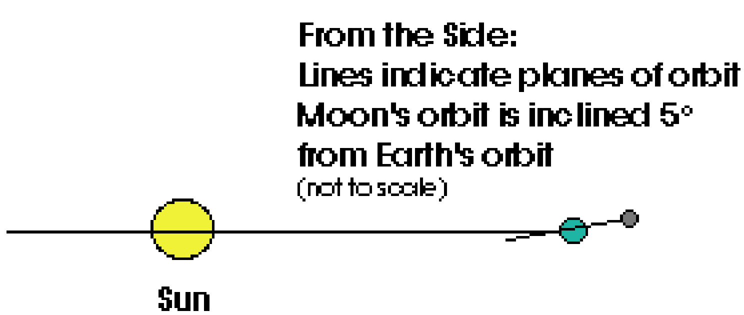


Notice that both the Sun and the Moon appear in the sky to be about the same size: half of a degree. You can figure this out yourself, because the system has scaled itself. The Sun is around 400 times the size of the Moon in diameter. But, the Moon is about 400 times closer to us than is the Sun. These cancel out distance effects and scale the apparent sizes of the objects in the sky to the same size. Great! This means, geometrically, that if you could line them up one day, you could blot one out with the other. Because of the distances involved, which one would block the other? The Moon would block out the further Sun. What about when the Moon is on the other side of the Earth? The Earth would cast a shadow on the Moon when they were all three lined up.

We've tried to draw in the rays of sunlight coming off of the Sun to demonstrate how it comes from the Sun in all directions. See the rays hitting the Moon straight on? These would normally cause a spot the size of the Moon to hit dead on the Earth. However, the Sun is large shining ball, so light can reach the Moon at other angles than just straight on. This effect causes two shadows to form from the Moon. The darkest part where no light is passing at all is called the umbra. The larger shadow, which you can see still gets sunlight in places so it is not as dark, is the penumbra.

When the Moon blocks the Sun, we call it a solar eclipse. (A lunar eclipse is when the Earth's shadow lands on the Moon.) What would a solar eclipse look like from space? What phase is the Moon for a solar eclipse? It is in New Moon (and conversely in Full Moon during a lunar eclipse.

Does the Moon always block the Sun each time it moves into the Sun-Moon-Earth alignment? Do you experience an eclipse of the Sun each month? No. Why not? As it is, the Moon does not orbit in the same plane as the Earth orbits the Sun; the Moon orbits 5 degrees tilted to the Earth's orbital plane. So that small number of degrees is enough to limit the solar eclipses to around once a year. The fact that the Moon's shadow is so tiny also means that the number of solar eclipses which happen for a certain place are also limited. People who want to view a solar eclipse usually have to travel to go see one. Lunar eclipses, however, are easier to see, since the shadow of the Earth on the Moon is quite large.



This is a Stickup!

Purpose

In this Thread, we are continuing to examine the passage of time from observations we can make about the outside world. In *Hello, Sun!*, we saw that the Sun appears to jog across the sky during the school day. It looks like a nice and smooth motion. By using the shadow of the Sun during the day, we may make safe and accurate measurements of that motion. The National Standards require that students be learning what causes light, heat and shadow, and how time passes, how to use rulers and other measuring tools. The vocabulary words which can be introduced to help us talk about our experiences are line, length, angle, sphere, straight, and model.

You will need: pencils , construction paper flags, flashlights, paper, and either a 12-inch stick/ruler or half-meter stick; 2-4 additional: chalk or wipe board, chalk/markers, big roll white paper, coffee can filled with sand, tape, flashlights/toothpicks/clay/paper enough for half the class number; 4-6 additional: easel, protractors, yarn or string, a calculator with trigonometry functions (tangent/co-tangent).

The class will initially need a sunny day for this with repeated measurements throughout the day every hour, starting with the earliest hour in the school day. You will need to have previously located South in the school yard. Materials gathering time is minimal since most of the materials are common in the classroom.

In the classroom, you will want to spend several class periods over a week or more exploring your data and what it means. The older your grade level, the more time you will want to spend. There is a lot of good math which can be introduced in this Thread and taught simultaneously. The procedure described in the Investigation portion of this Thread should be repeated at least three more times during the year.

Teacher Background

We have already explored the way the Sun moves in the sky during the day. The next step is to try and see that motion from another perspective. Some classes may have been able to determine the height of the Sun in fists and found that the Sun first gets higher then lower in the sky. Did students also notice that their shadows got shorter and then longer again? Do they have a record of that? As we saw from the Thread, *Me and My Shadow*, the height of a light source changes the lengths and orientations of shadows. Using a standard stick with careful measurements can give us a better record of the changing shadow lengths outside in the Sun and also good data for exploring deeper.

A day's worth of sunstick shadow measurements will produce a shadow pattern which will look like a fan of lines, first long then shorter then longer again. This fan will begin with its first shadow line on the left of the stick, if you are looking from South of the stick. This fan pattern will then proceed with lines moving ever more to the right and at steeper angles to the edge of the paper. This is because the Sun rises in the East, or to the right of the stick. A light source on the right will cast a shadow of an object to the left. The angle of the Sun above the horizon determines the length of the shadows it causes behind objects. The higher the Sun is, the shorter the shadow. This is why the fan gets shorter at mid-day. In fact, if the Earth did not tilt on its axis 23.5° as it does, then the Sun's height at mid-day would be the same every day of the year. The Thread called *Latitudes and Attitudes* will let us explore this further.

You will be calculating tangents of angles for the upper grades. In a right triangle (one with a 90° angle in it), the tangent is defined as the value of the side of the triangle opposite an angle divided by the side of the triangle adjacent to the angle. Neither of these sides is the hypotenuse, or long side, when you are measuring the angles.

As part of the ECT curriculum, we offer some lessons about how ancient and historical cultures used observations similar to those the students will make in the Threads. For *This is a Stickup,* you can use the background information and classroom activities written for *Hello, Sun!* relating to how Scandinavians one thousand years ago used the Sun to tell time. We call it **Telling Time without a Clock**, and it is a module found in the Additional Resources.

> "Cherish [Science], venerate her, follow her methods faithfully ... and the future of this people will be greater than the past."
>
> —Thomas Huxley

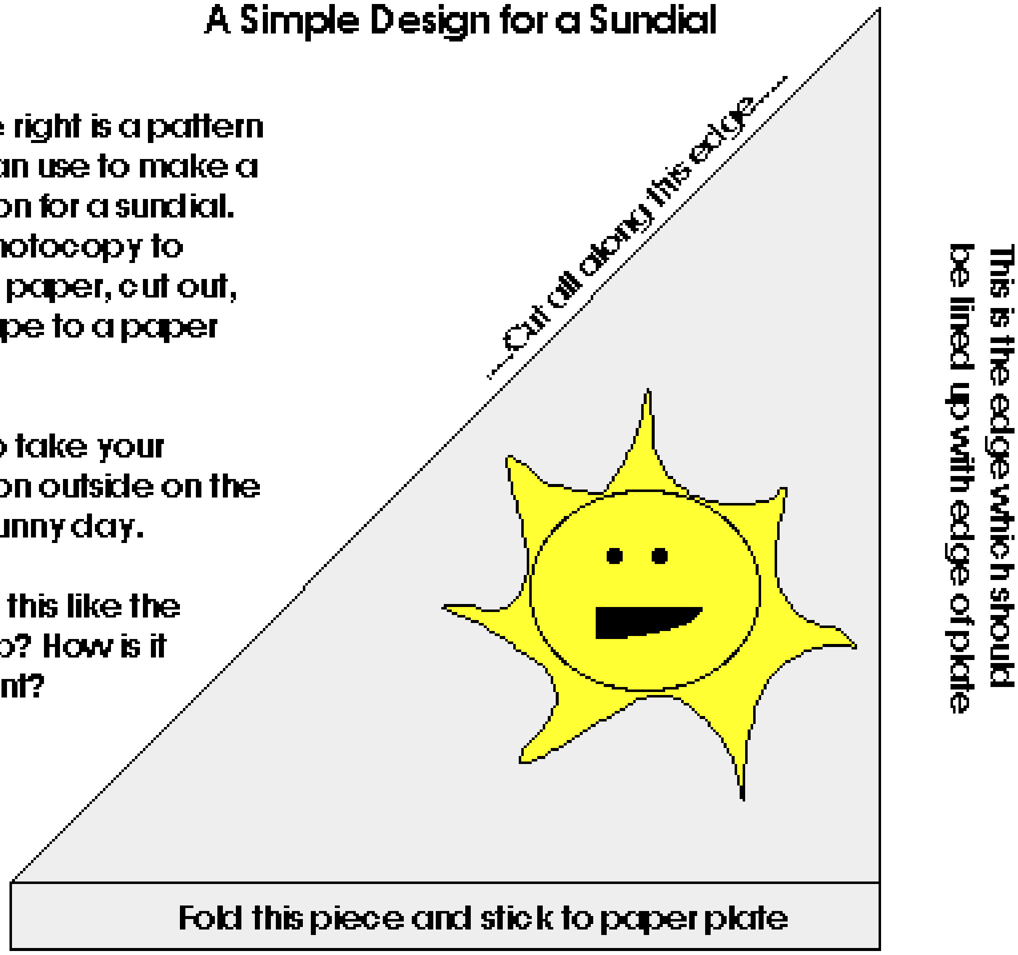
> "Nature is a language and every new fact one learns is a new word; but it is not a language taken to pieces and dead in the dictionary, but the language put together into a most significant and universal sense. I wish to learn this language--not that I may know a new grammar, but that I may read the great book which is written in that tongue."
>
> —Ralph Waldo Emerson

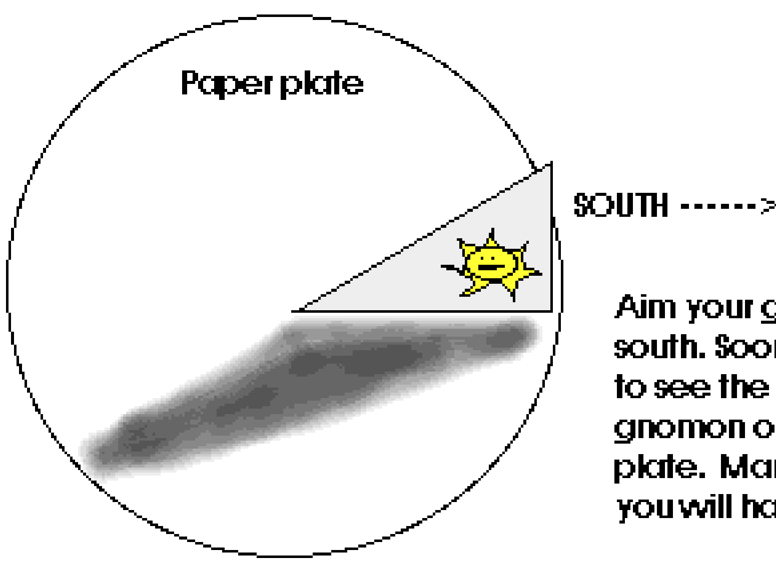
A Simple Design for a Sundial

On the right is a pattern you can use to make a gnomon for a sundial. Just photocopy to heavy paper, cut out, and tape to a paper plate.

Plan to take your gnomon outside on the next sunny day.

How is this like the Stickup? How is it different?





Aim your gnomon towards the south. Soon, you will be able to see the shadow cast by the gnomon onto the paper plate. Mark every hour and you will have made a sundial!

Kindergarten through Second Grade

Developmental Issues

This age group cannot yet manage the precision required for the Investigation in this Thread. They will not be able to make good measurements nor understand their importance. What we want them to learn from this adventure is that as the Sun moves across the sky, the Sun's light changes the stick's shadow, something which they should remember from *Me and My Shadow*. However, we can emphasize using the Sun as a clock in this Thread. It is suggested that instead of employing the measuring stick and paper that you instead use a sapling or pole in the school yard and bright marking objects or flags. This way we can express the same basic concept in a very big and personal way, using first our bodies to mark where the shadows are and then special flags we place to make semi-permanent records of the shadows. Decorating personal flags would be a fine integration of art into this Thread for this age group.

Inquiry Introduction

What is happening to the Sun outside during the day? Is it staying in one place? Does it seem to move? What happens to our shadows if the light moves? Do you think our sunlight shadows could move, too? What if we move? Do our shadows move with us? Does the Sun/Blocker/Shadow game work if we move? How could we try it out? How long would it take before we noticed any movement? Can we actually see the Sun moving? How long did it take in *Hello, Sun!* before we noticed the motion?

Inquiry Investigation

Arrange ahead of time for your observation place to be undisturbed by students during the day and recess. Perhaps alerting your principal about the activity will help. Outside, let's pick a short tree or pole on which the school's shadow does not fall anytime during the day. It would be best if this object were near the place where we all did *Hello, Sun!* so similar horizon landmarks are around us. This will help us understand what is going on.

What time is it? Where is the shadow of our tree? Can we all go run to the shadow and stand on it? How long is the shadow? Could someone go stand at the very end of the shadow? Place a little class flag there with the time written on it. Who thinks the shadow will be somewhere else in an hour? Where? Stand on the spot you think it will be. With our names on our own flags (of a different color than the class flag), let's each place a flag down where each of us thinks the shadow will be in one hour. Pick random students' flags and ask them why they chose that spot. Could they relate their decision to the Sun at all? Where do we think the Sun will be in one hour?

In one hour, go outside again. Where is the end of the shadow? Mark this with another class flag. Who was closest? Which way did the shadow move? What is changing? Where is the Sun? Did the tree shrink or grow? Let's retrieve our personal flags. Where might the shadow be next hour? This time students may begin to see that a pattern might be forming, and many will put their flag to the right of the second class flag. Again, ask them why and if they can relate it to the Sun.

By the third hour out, it should be clear what is happening to the pattern of the shadow. The shadows are moving to the right. The length of the shadow is not going to make much sense to them, since it involves the height of the Sun; pointing out the correlation will be difficult. However, with flashlights inside, repeating the You Light Up my Life investigation may allow more modeling of the situation. Consider this if you feel your students might gain insight. Otherwise, it is not crucial at this age group. These are understandings they can build as they get older.

Which way did the Sun go today? Which way did the shadow go? Did the tree move at all during the day? No … so what happened? Play the Sun/Blocker/Shadow game again inside with a flashlight, some object, and paper. Model the experience from outside with everyone. Ask them every step of the way if this is where the Sun was and this is where the tree or pole was. Which way did the shadow go? Is the Sun going that way? Does it happen like that for everyone in the whole world?

> "Reason is experimental intelligence, conceived after the pattern of science, and used in the creation of social arts; it has something to do. It liberates man from the bondage of the past, due to ignorance and accident hardened into custom. It projects a better future and assists man in its realization. And its operation is always subject to test in experience... The principles which man projects as guides... are not dogmas. They are hypotheses to be worked out in practice, and to be rejected, corrected and expanded as they fail or succeed in giving our present experience the guidance it requires. We may call them programmes of action, but since they are to be used in making our future acts less blind, more directed,they are flexible. Intelligence is not something possessed once for all. It is in constant process of forming,and its retention requires constant alertness in observing consequences, an open-minded will to learn and courage in re-adjustment."
>
> —John Dewey

Second Grade through Fourth Grade

Developmental Issues

This is a good Thread for this age group. They are beginning to learn about numbers and how to use measuring tools. At this age they are extra keen not to make mistakes, since they are desperate to fit in and avoid looking stupid. And they want to be given real tasks to do. These characteristics make a subset of this Thread perfect for your students. We will not delve into this situation's geometry with these students, but we will let them participate in some serious observing, building, and modeling in a way which we hope will satisfy their intellectual desires.

Inquiry Introduction

How does the Sun seem to move during the day? From where to where? Recall the *Hello, Sun!* blackboard drawings? Could anyone draw them on the board? So, since we were facing South, the Sun moved from left to right. What happens to shadows made by the Sun during the day, then? How could we observe them and be able to take them inside to look at? Can we take somebody else's shadows inside? How could we do this? Gather suggestions from them. Many will recall that we were able to take the Hello, Sun! data indoors because we made a record of it. How could we make a record of the shadows? They will suggest putting paper on the ground, perhaps, or taking pictures. Will one picture be able to show us all of the shadows from a whole day? No. A piece of paper would work, if it had all of the shadows on it. How big a piece of paper? How long are shadows? And what should we use as a shadow maker?

Look around the room and find a meter stick. How could we keep this stick from falling over? A can with junk in it to keep the stick still is a good idea: things like clay and rocks, a Styrofoam plant basket block and stones, or a coffee can filled with sand are good ideas. Paper from a big roll and masking tape will be good for the record keeping. And a nice new marker.

Inquiry Investigation

Time the observations to coincide with the times we all went out for Hello, Sun! Bring all of the materials outside. Find the location from Hello, Sun! and put your equipment down there. Pull out a large sheet (about four feet long and as wide as the paper itself) and lay it down with one corner pointing towards south. (Human symmetry ideals would want you to put it square with a side facing south. Don't give in. Since the shadows at morning will be longer than those in mid-day, you will need to account for this in the orientation of your paper.) Tape the paper very firmly down. You may want to mark where the edges of the paper are in case it blows out of position. Put the can down in the corner. Make a careful circle around the bottom of the can so that you always know where it is supposed to go.

So that we don't all crowd the paper with our shadows, let's stand on the north side of the paper. (There is no need to call things north and south with this age group. They will get all fuddled up with the vocabulary. You might say, “Let's stand at the top of the paper.”)

What time is it? Someone look at a watch. Where is the shadow here? Trace the shadow line carefully with a dark marker. Write the time at the shadow's end. (Do this for every shadow observation today. Putting the date down near the bottom of the paper is probably a good idea.) The shadow is to our right. Where is the Sun? It is to our left. How long is this shadow? Where do we think the shadow will be in one hour? Does anyone recall *Hello, Sun!* and what we learned about how the Sun moved in the course of one hour? What might that do to the shadow? Will the Sun be higher in the sky? What might that do to the shadow? The students may want to place stones on the paper marking where they think the next shadow will be. If they think the shadow might change size, they should place their stone where they think the end of the shadow will be.

Back outside again in one hour … where did the shadow move? How many things outside in our set-up could be changing? Let them decide if the stick could have changed size. Could the paper have changed size? What else is changing? Are people attempting to locate where the Sun is (remember to not look directly at the Sun)? Is there a connection? How long is the shadow? Where in the sky is the Sun?

Back in the classroom, retrieve the Hello, Sun! easel drawing. Leave it in view during this day as a reference guide for students. What time did we make this last observation? Can anyone find it on the *Hello, Sun!* drawing? How high is the Sun now as compared to one hour ago? Did anything happen to the shadow during this last hour? What might be the link? They may or may not see the height and length relationship right away, so encourage more thinking until they propose the idea. When they do, ask them when they think the shadow might be the shortest today, or when it will be the longest. If they do not see the connection yet, revisit this line of questioning after each observation outside until they do.

After a completed sun stick record has been made (i.e. at the end of the day) tape the record up in the classroom. Tomorrow we will be thinking more about this day and building our own models of it.

The next day, set aside a table for the flashlight/toothpick/clay/paper materials and begin talking with the class about our experiences from the previous day. What did we do yesterday and what do we think we have discovered? We think we discovered that as the Sun moved across the sky and up and down in the sky, the shadows moved across the paper and got longer or shorter. How could we try to model that inside the classroom? We would need a Sun, right? What if we wanted everyone to have his own Sun? What could we use instead of a Sun? What is the Sun anyway? They should hopefully recall their experiences with You Light Up My Life well enough to know that light is light, whatever its source, and that objects in the path of flashlights will cast shadows just as they do in the path of sunlight. What else do we need? We need some kind of little stick stuck into something. A toothpick in clay works well. And we need paper and markers. No problem.

In teams of two, have them gather one set of materials and bring them to a desk or table. Can they recreate what happened outside? Give them plenty of time to fiddle with the materials. They will want desperately to play with the flashlights at first, but not as badly as they did in You Light Up My Life. Ask them to focus on recreating the events of yesterday. What must they do with the flashlight to get their toothpick shadows looking like those on yesterday's record taped to the wall? Have them tell you why they built their model the way they did and how they constructed it. Perhaps teams could later come to the front and explain their models to the rest of the class.

What can we see here? Grab someone's flashlight and aim it down from above the very top of the toothpick. What kinds of things would happen to the shadows if we did this? There would be no shadow. Does this happen on the Earth anywhere? What about if we really lowered the flashlight (aim it at the side of the toothpick and very low). The shadows would be very long. Does this ever happen on the Earth? Gather their suggestions. Ask that they write up their experiences from the past few days, especially what they think they learned and what more they might want to learn about how shadows work on the Earth.

> "[Young persons] grow up in libraries, believing it their duty to accept the views which Cicero, which Locke, which Bacon have given, forgetful that Cicero, Locke and Bacon were only young men in libraries when they wrote those books."
>
> —Ralph Waldo Emerson

Fourth Grade through Sixth Grade

Developmental Issues

These students are ready to make some serious observations about their world. This age group is able to record data and comprehend the need for careful observation. They are responsible and eager to master skills. The onset of puberty often hampers a child's desire to take risks. The simplicity of the observations and the obvious results as they come in provide a student with a comfortable experience in which to make some important predictions. The journal keeping is a very personal thing and can be a safe, private place also to record their ideas. Modeling our investigation in this Thread will help make some connections between the math we are doing and what it shows about the world around us. At this age group, most curricula are introducing basic geometry: triangles, circles, and some simple concepts associated with them. This Thread uses degrees, fractions, angles and triangles to explore the spin speed of the Earth, the height of the Sun, and later in the year, the tilt of the Earth. It is fairly important that the students be familiar with the protractor *before* this Investigation. By the time protractors are used in this Investigation, you and your class will be involved in some serious thinking and connection building. It will distract from the cognitive process to stop and learn about the protractor in the middle of the thread.

Inquiry Introduction

When the Sun moves across the sky, how could we really record its exact position? It is extremely dangerous to look directly at the Sun. How else could we possibly try to record the motion? Let's hope they are thinking about the Sun as a light source and that they know an awful lot about the characteristics of light sources now. If not, ask them if the Sun is a light. What do they know about light sources? What can lights do? What results occur when we put something in the way of the light? Is there anything important about the light we can learn from what happens to the shadow of the object in its way? We can tell how bright it is, sometimes, by the darkness of the shadow if the object is very opaque. What about the height of the light? If light travels in straight lines, what happens to a shadow if the light comes from up here? Aim a pretend flashlight up high above someone's head. This may not be obvious to everyone. Good. That means it is time to go outside and experience this all for ourselves.

Let's bring something outside which we know a lot about. Here's a piece of wood (the 12 inch dowel rod). How long is it? How could we know for sure? Have them suggest and implement the act of measuring it with a ruler. OK, so we know it is a foot long. Let's stick this outside and watch its shadows all day and measure them as well. If they did this kind of thing last year, they may pipe up and say so. Ask them if they ever measured the shadows they made then or if they discovered the speed of the Sun's movement? Well, no. OK, then. Time to roll.

Inquiry Investigation

Bring the easel and paper out again. Outside, with the materials set up in a good sunny spot, have them carefully pin down the paper somewhere safe where it won't be trampled. You might ask them which way is south. Suggest they point a corner of the big paper to the South and put the can with dowel upright near that corner. What happens if the can slips? What could we do to make sure we always know where the can goes? What happens if the paper slips? What could we do to make sure we know where the corners of the paper were? Taping the corners down and chalking the outline of the paper seems to work well. Also, outline the can on the paper. If it is windy, weights on the corners of the paper should be used.

What time is it? Where is the shadow? Have someone trace the shadow with dark marker very very carefully. Why so carefully? When we measure, we need to have a good record. Mark the time at the top of the traced line. We might all make some guesses as to where we think the shadow might be next time we come out to check our set-up by placing rocks or sticks on the paper.

Where is the Sun? Have a team draw the horizon on the easel as seen from the spot in front of the stick (i.e. the sky's southern hemisphere). In that case, what might we want to know about where we are standing with the easel? Have them make some mark on the ground so that they can stand in the same place again after one hour. Ask them to draw the Sun in, using the "fists" technique from Hello, Sun! Where will the Sun be in an hour? They will point to some spot on the paper. Let's keep this drawing going along with the sun stick record. So, where might the shadow be after the Sun has moved for an hour? And the length of the shadow? Longer, shorter, or the same? Why? Gather ideas but don't encourage any one over another. We'll soon see in an hour!

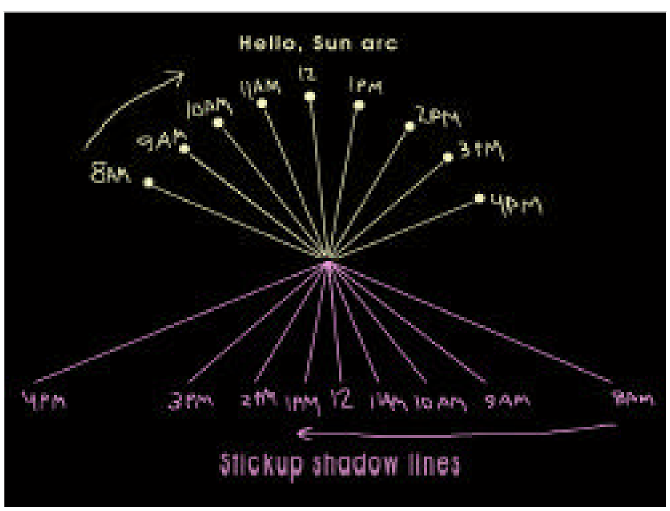
In one hour, revisit the set-up. Before we trace the shadow, what might we want to do? Check that everything is in its place. Then have someone trace the shadow carefully, marking the time at the top of the shadow line again. So, what happened here? Tell me about how the new shadow is changed from the last one. Someone will tell you that it moved and that it got shorter. Why did it do this? Did the stick move or get shorter? What is the only thing that can change the shadow? The light. So, the light moved in some way. Where is the Sun now? Have the Sun keepers stand in their spot and draw the Sun in on the easel. Is there a connection? If no one sees that when the Sun moves to the right, the shadow moves to the left, that is fine. We can just keep saying these things. Also, how many "fists" high is the Sun? How long is the shadow? What is happening here?

Each successive visit outside will become less interesting to them until the shadows get longer again. Why is this happening? Do we now make the connection? How could we model that inside of the classroom? They should think about this for tomorrow, for we will be building our own models then and discovering some things about the world from them. For homework, you may have them write in their journals what they think happens during the day to shadows and the Earth and Sun. Can they imagine what shadows would be like somewhere else on the Earth? Before they arrive for the next day, tape the easel drawings to the wall above the sun stick drawing (in the diamond orientation).

The next day, ask them what happened yesterday and what they think they now know. Show them that you put up the drawings we made so that they are just like they were when we saw them on the ground. Have them think about (but not call out) the two positions the drawings have been in.

Break the students into teams of four people, hand out the sets of sun-stick models (flashlight/toothpick/clay/paper) and have the teams rebuild the set-ups. How can we recreate the scene with flashlights? Where did the Sun come up this morning? Where did it go and how high? When were the shadows the longest? The shortest? What is the real connection? Have them tell you what they think is happening. They will say things like, "When the Sun is highest, the shadows are shortest." Ask them why. Does it have to do with the nature of light? Can anyone draw what is happening in their model or outside on the board?

Help by drawing the stick in the middle and put the Sun on the far left. Ask someone to come up and draw how the light is coming to the stick. Ask the class where the shadow is. They will want to come up and point or draw it in. Extend the sunlight lines past the very tip top of the stick line (if they are not past it already) so that they reach beyond and mark the end of the shadow. Ask them about shadows again and what they learned from You Light Up my Life if they wonder why you are asking that. Flashbacks are no problem, and are always encouraged. When everyone understands, draw the Sun higher and over more to the right. Have someone else come up and draw how the light is coming to the stick. Where is the shadow now? And so on.



Tape to the board next to the chalk drawings (but higher up) the easel drawing of the Sun. Underneath this, tape the sun stick drawings for comparison. Is this what we saw? Yes. What has happened is that we have experienced something and set it aside. We then modeled it and thought about it in lines and direction, and set this next to our first experience. What was true for one is true for the other, and *vice versa*. Since these two experiences support each other, each view is as valid as the other. The next step is taking a trip to the third realm of experience: the mathematical one. How could we communicate our experience in terms of mathematical models?

Isolate one section of the chalk drawing on the board (by either erasing the rest or re-drawing the key parts) so that it looks like a little triangle formed from the sunlight line zooming past the top of the stick, the sun stick itself, and the line marking where the shadow was cast. What shape is this? A triangle. What do you know about triangles? What does the word itself say to you? Tri = Three, angle = some height measured in degrees. Point back to the drawing on the board. Which angle opens up and points to the Sun's position?

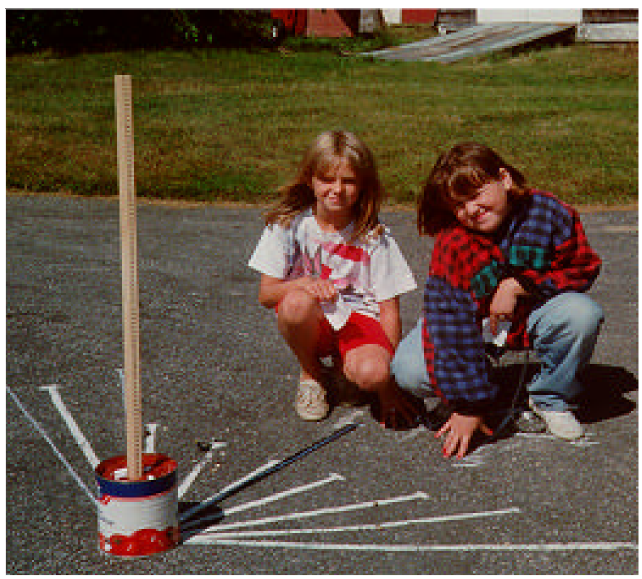
Draw a Sun high on the board. Ask some class members where the stick's shadow would be on their model if this Sun could give off light? How could we test this? Hopefully, they will use the flashlight in their hands and move them so that they are in line with the Sun mark without leaving their desks. So, how high is the flashlight or the Sun mark above the paper in degrees? Trace the line from the Sun to the end of the shadow—but with what?

It would be good to trace the length of the shadow with a pencil first. Then, have one person hold the flashlight while another holds a string to the flashlight near the lens. A third person should pull the string until the other free end reaches the tip of the shadow drawn on the paper. What is the shape made by the string, the toothpick, and the paper shadow outline? The fourth person should be able to see this shape by viewing the whole construction from the side. What does the string represent? It points to the Sun. It follows that an angle formed at the corner by the string and the paper "ground", represents the "Sun's" angle above the ground. Can the fourth person see how this is possible by following the line made by the string up to the "Sun"? Can she explain it to everyone else in the group?

Have the fourth person in each group take a protractor and measure the height of the Sun (or the string line, in this case) in degrees. How high is our Sun in degrees above the paper? How long was the shadow? Let's record these numbers on the bottom of the paper somewhere. Erase the first Sun and draw another significantly lower on the board and redo this entire procedure for that new height. What does this triangle look like? How is it different from the first one? What is the height of our Sun? What is the length of the shadow?

What is happening here? There must be some relationship between the height of the Sun and the length of shadow it makes, but we knew this from our experiences outside. There also seems to be some mathematical relation between that angle of the triangle and the length of the triangle's bottom side. Did the size of the toothpick ever change? No. This makes a steady length for one side of the triangle. Maybe we could think about that some more. Is there a fraction we could think about that might change as the small angle changes? How about the toothpick length divided by the shadow length? What is the number? Is it greater than one here (for the first set of numbers, write them on the easel as a fraction.) How big was the angle? And what about for the other set? Write them on the easel also (if there is any room left, that is!). How big was its angle? We seem to find that the bigger the angle, the bigger the fraction. Cool. Do we have any other data we can check? Let's gather all of our data in one place so we can look for patterns, if there are any!

Start a table on a new sheet on the easel. The table should have room enough for 7 columns, with **Time** and **Length of Shadow** and **Length of Stick** as headers for columns 1-3. Obviously, the third column will not change! Let's think about how we have gotten data so far. The first column we know because we were careful to write down the time each time we took a measurement. The second column we had to measure ourselves with a ruler. The third column we knew already, because we had measured the stick. What else have we been talking about that we can figure out about this system of three lines, stick, shadow, and ray of sunlight? They should continue thinking about the idea of the triangle and that fraction.



How might we really find the angles we want to know about? Does anyone suggest using the string idea on the real setup? Set up the stick and paper on the floor. Let students use string to connect the top of the stick to the end of the first shadow. Someone can then measure the angle made at the paper with the string and write this into a **measured angle** column. They should do this for all of the shadow lengths.

Look only at the sun stick drawings, not the *Hello, Sun!* set. How long was our stick? It was one foot, or 12 inches, or 50 centimeters, if you used the half-meter stick. What are the lengths of these shadows? A group should measure the lines and record the lengths in the table. Can they make a fifth column for the **fraction** and fill it in? If not, you might consider using a calculator and giving them fractional values for the numbers they call out. Is there a pattern? Could we make some guesses based on the sizes of the fractions as to what the angles might have been for those times?

We are so close to being able to find an angle from this information, even though we have one we think we measured correctly. If this relationship is so simple, is there a table somewhere? Producing a table of tangents might be cool. It is not possible to expect these students to read the table very well, nor is it reasonable to expect them to understand radians of a circle. So, it is suggested that you instead tell them the calculator has the table built in. Yes, really. And for each fraction we find, we can find the angle that goes with it. Do this for each tangent fraction and write the **calculated angle** in on the easel in a sixth column.

The trick here, if they have not suggested it already, is that the Hello, Sun! drawing has fists drawn in to indicate height. Since a fist is about 10 degrees, we can see how the angles match. If someone can call out the fist measurement, the rest should be able to tell you the degrees. Write **fist degrees** into the seventh and final column. The two last columns will not be perfectly matched, but they will be close. Ask them which measurement do they think is the less accurate and why? The fists, obviously, because the variables are the measurer's accuracy and hand size. Those who recorded the Hello, Sun! drawing should not be made fun of at this point, but should be reminded that if their eyesight were as perfect as the math, they would be in the Guinness Book of World Records! Human error is a fact of life. How could we have made mistakes in the math? The way we typed data into the calculator, the way we measured the shadow length, or the wiggling of the sun stick outside in the first place.

What are we looking to find out from this work, anyway? Probe the class for what ideas they might be having about why we are doing this today. Some may think about the height of the Sun changing, because they can see from the *Hello, Sun!* data that it is. Some may think we are trying to learn more about triangles and angles. Others may think this is a load of malarkey. OK, two out of three isn’t bad. The gist is to see if we can use three different means of finding the same answer, to prove that if the logic is correct, there are several methods to find the same answer. So many times we discourage children from using their own problem solving techniques because we ourselves have not internalized their method enough to comprehend if it is sound. Hopefully, after this investigation, students will see that a few minutes of thought can create three separate means of finding the same value for the Sun’s angle.

Encourage your class to think about how each method was different in terms of accuracy, levels of math and observation, and simplicity.

The last thing to think about with this single data set is the time it took for the Sun to zip across the sky or the shadows to zip across the paper during the day. The pattern of shadows makes a big fan on the paper. How would you use the protractors to find out things about the pattern? Are there any places where you would want to measure angles? Let them measure for a while. Then ask what is the biggest angle they can find. It will be the angle between the first and last shadows. What is this angle? What does it represent about the Sun itself? How long did it take the Sun to travel that far? Subtracting the times listed on the shadows, it is (if you measured from, say, 9 a.m until 2 p.m.) five hours. How many degrees is that? 75 degrees.

How many degrees is it around the Earth? It is 360 degrees, because the Earth is a ball. So how far around the Earth did the Sun appear to scoot in five hours? (Of course, it is the Earth spinning around like a top past a steady Sun.) Give them time to puzzle with this. Some will ignore the 360 degrees and use the 5 hours instead, knowing a day is twenty-four hours. They can divide 24 hours by 5 hours and discover that 5 hours goes into 24 hours almost 5 times. So, the Earth almost went one-fifth of the way around on its axis past the Sun. Others will divide the degrees traveled in five hours into the degrees around the Earth and also give you a fraction of almost one fifth. Are both answers right? Of course they are.

How could we find out how many miles of Earth spun past the Sun in five hours? We'd need to know how many miles around the Earth is. Is there any way to find that out without looking it up? No, not yet. We need another measurement from *Latitudes and Attitudes*. For now, let's use a circumference for the Earth of 25,000 miles. So, in our example, in 5 hours, about 5,000 miles of the Earth's surface would have spun past the Sun!

Measure the shadow lengths again around the time of the winter solstice (about December 22), recreating the steps you or your class did for the autumn equinox. After they have also observed and measured the spring equinox (about March 21) shadow lines, begin the discussions for the end of the Thread *Tilt-A-World*.

A note about the autumn equinox (about September 22): Since you are likely to have read this entire package ahead of time, here's a note for you. If your class has not reached this Investigation before the autumn equinox, please attempt to build and make your own record of the sun stick shadows on that day. If there are other teachers in your school who are participating in this curriculum, they could help you keep up the observations or at least watch your classroom while you run out to make these records on the equinox. You should try to measure the fist height of the Sun each time you go out, just as the kids will do. No need to measure your lines; they can do that themselves when they do the others. Curious students will want to know what you are doing, and you can tell them that soon they will be doing it as well. If it is really impossible for you to get autumn equinox data, then what is there to do? You will have two sets of data to use and not three for the next Thread.

Related Internet Sites

Sites include online projects about shadows and latitude and also live cameras to demonstrate the day/night changes all over the Earth!

http://www.ed.uiuc.edu/coe/projects/noon-project/
Noon Project —Here's information about how schools can join in making calculations of the size of the Earth from sunstick data.

http://www.cmi.k12.il.us/Urbana/projects/UHSArt/mic3/sundialproject.html
Shadow Project — This is a sundial project done at Urbana High School. They have some interesting ideas and links here for learning about the sun clocks.

http://www.eduplace.com/projects/shadow2.html
Shadows and Latitudes — A formal online project for collecting shadow length data and collaborating with people around the world.

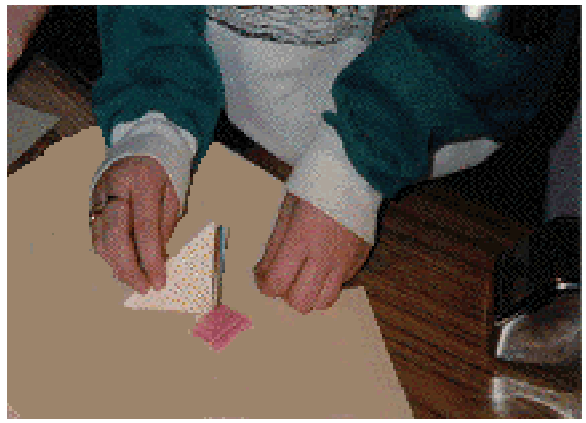
http://hea-www.harvard.edu/ECT/nightday.html
Night and Day around the Web — This is a summary page of the best live cameras around the Internet.

http://www.ed.uiuc.edu/courses/satex/sp96/noon-project/Eras.html
Erastothenes — Read a story about how Erastothenes and friends calculated the circumference of the Earth using shadow measurements.

Joke: "There is a theory which states that if ever anyone ever discovers exactly what the universe is for and why it is here, it will instantly disappear and be replaced by something even more bizarre and inexplicable. There is another theory which states that this has already happened."

—Douglas Adams

Latitudes and Attitudes



Purpose

This Thread invites us to explore the effect our latitude has on the shadows we get from the Sun. We will learn from this experience that the shape of the Earth must be curved in some manner to account for the different lengths of shadows at different latitudes and that the Sun is very far away. The National Science Education Standards mandate that students should understand the motion and positions of the Earth and how they affect the path of sunlight we get in different places. Students should also be thinking about how life is affected by the changes on the Earth. This Thread's use of models and the Internet also answers Standard requirements concerning technology and the building of equipment. Vocabulary which can be introduced to help us talk about our experiences are latitude, altitude, angle, triangle, sides, and parallel lines.

Teacher Background

Latitude is easy to understand with a globe in front of you. Notice you can divide the globe in half anywhere so that it will make two symmetrical pieces. We call the imagined horizontal line running around Earth's middle the *equator*. See that any other horizontal lines imagined above or below the equator divide the globe unevenly. Such non-equatorial lines are referred to in terms of their distance from the equator. A line called 20° North would tell you that this line is somewhere north of (or "up" from) the equator at a distance measured not in miles, but in degrees. In other words, this distance represents some angle. Where is this angle measured from?

> You will need: globe, blue-tak, miniature tree-shapes made from toothpicks cut in half, overhead projector, flashlights; Grades 2-4: blue-tak, clay, enough golf tees for half of the class, globes, paper, pencils, flashlights for half the class, Grades 4-6: manila paper, computer with Internet WWW browser or cities packet, golf tees, blue-tak.
>
> Some time outside is needed to recreate the Stick-Up! observation. You will also need several class periods to really explore this challenge in perspective. Also, computer time may be required to retrieve data from different countries, unless you use the cities packet. Collecting materials may take an hour or so.

If we pick a point on the equator and connect it back to the center point of the globe, we would have a kind of line commonly called a *radius*. This radius would have an angle of zero degrees, because it is stretched flat from the middle of the Earth to the equator. A line (or radius) stretching straight up from the Earth's center to the North pole of the Earth would measure 90° N. Can there be any angle from the Earth's center higher than that? No. What if we connected all the points 20° above the equator to the center of the Earth? They too would make radii, but these would be at 20° angles to the flat radii running out from the Earth's center to the equator. This is what is meant by 20° N latitude.

The height of the Sun above the horizon is determined by several things, one of them being the position of the viewer on the Earth. The further the viewer is from the equator, the lower the Sun will appear in the sky. To understand this, we must first recall that the Sun is a huge sphere 93,000,000 miles away. Its light comes to us as direct rays. With a non-tilting Earth, this would mean the direct rays would hit the equator dead on, and the viewers there would see the Sun directly overhead, while elsewhere along the curved Earth other viewers would see the Sun at some height over the horizon, but not directly above them like at the equator.

This is easier to understand if we think about an imaginary line cutting the sky in half. This sky equator would be right over the Earth equator, slicing the sky into two half-spheres, as if the Earth equator were a big disk stretching out into space. The Sun would travel along this sky equator around and around right above the Earth equator if the Earth were not tilted. Those of us not living on the Earth equator would have to look somewhere other than directly overhead in the sky to see the Sun's path. Just as we would have to look lower on the Earth (in the northern hemisphere) from where we are to find the Earth's equator, we would have to look lower in the sky (as opposed to directly overhead) to find the Sun. With globe in hand, imagine that sky equator disk jutting out from the Earth equator. Now, imagine you are walking from the equator north, to someplace like Boston. When you began, you were directly under the Sun. In Boston, your sky would be different, with the Sun's path in the South part of the sky, closer to the horizon, and not overhead.

The other factor determining the height of the Sun's path is the Earth's tilt. Most of the planets in the Solar System spin on an axis which is tilted over compared to the plane in which they orbit the Sun. The tilt of the Earth's axis is 23.5°. This is a rigid tilt, which means that the Earth always seems to tilt over 23.5° in one direction only with respect to the stars around it. So, as it goes around the Sun, this tilt orientation makes the Sun's height change an awful lot during the year, since tilting towards or away from the Sun causes the Sun to appear respectively higher or lower in the sky. But understand that the Earth is not rocking back and forth! It is just the fact that the forward tilt axis (of the North pole) is always along one straight line, while the Earth is going around the Sun in a roughly circular path. This means the Sun will sometimes be in line with the forward tilt of the pole and other times it will be not in line and still other times it will be opposite of the forward tilt direction.

When the Earth is in a section of its orbit around the Sun where the Sun is in line with the forward tilt of the pole, then places in the Northern Hemisphere have a higher Sun in the sky, hence a longer arc for the Sun to go through across the sky. This results in a longer amount of sunlight (longer daylight time in summer), and hence a longer time to heat up the surface. This causes warmer temperatures; this is summer. In contrast, when the Earth has orbited around the Sun to the section where the Sun is in the opposite direction of the forward tilt of the pole, places in the Northern Hemisphere will see a lower path of the Sun in the sky, hence a shorter arc for the Sun to go through across the sky, hence a shorter time to heat up the surface. This causes cooler temperatures, this is winter. So, what is happening to the Southern Hemisphere? With the Sun’s view of the Earth’s top tilting back, the southern areas of the planet are tiltling towards the Sun, just like bending backwards and having your tummy sticking out! So, the Southern Hemisphere is getting warmer with a higher Sun arcing a longer distance across the sky. What about when the Sun is in line with the tilt arcing towards it? Well, then the Southern Hemisphere is having winter.

What about in between these two seasons? The Earth has moved into a section of its orbit where the Sun is not in the direction of the forward tilt of the pole, nor is it in the opposite direction. There is no extreme Sun height during these times of year which we call fall and spring. For one day in both the spring and the fall, the Sun strikes directly over the equator. No part of the Earth is tilting toward the Sun. The only affect on the height of the Sun is the fact that the Earth is a sphere, and we all live somewhere along the curve. The special day is called an *equinox*, meaning equal night and day times. The day is exactly 12 hours long, making the night 12 hours as well.

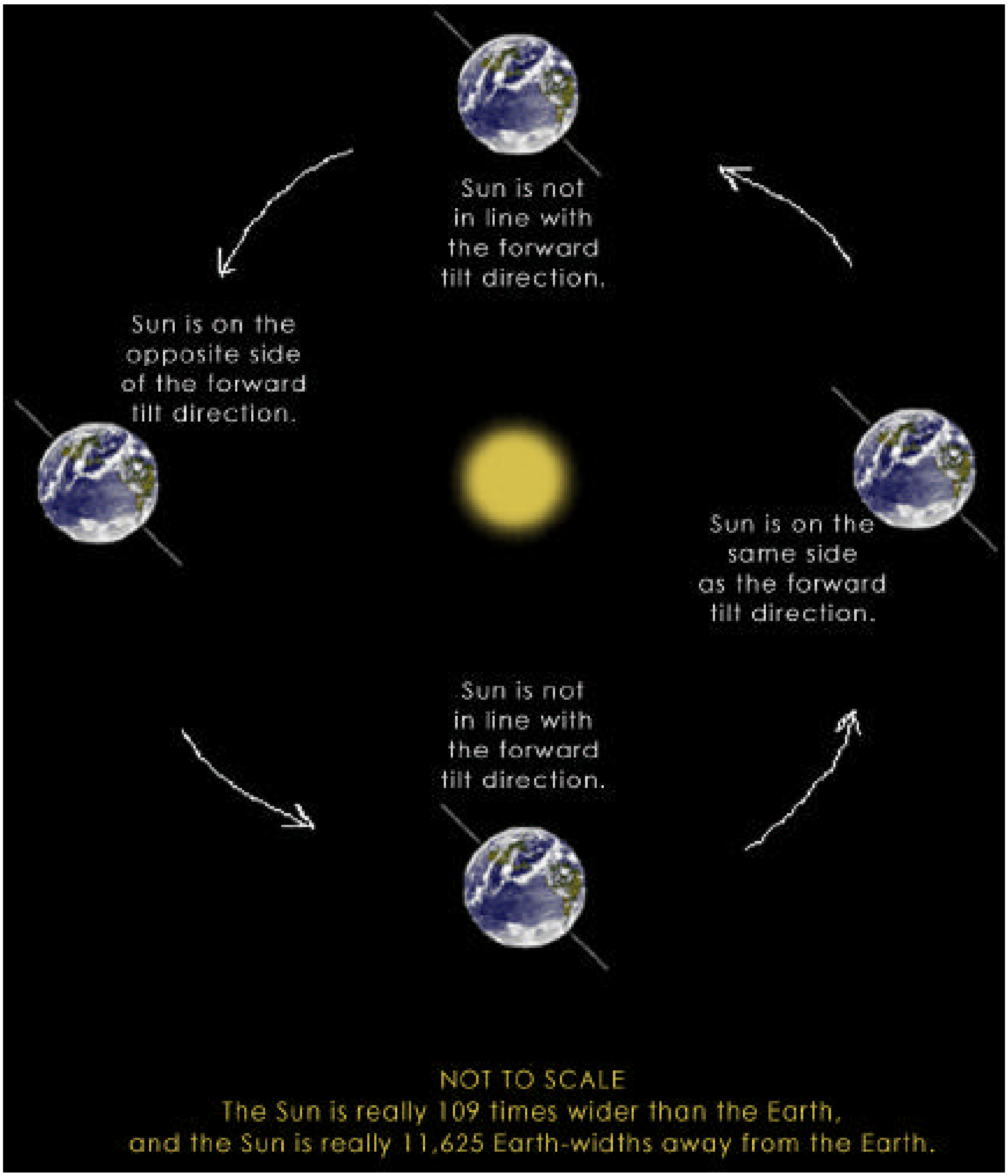
Why do we care about the equinox? What we learned from *This is a Stickup!* is there’s a link between the length of a shadow and the height of the Sun. We can measure a stick's shadow on an equinox and get the height of the Sun. On these special equinox days, it is possible to measure our latitude, since the tilt factor is non-existent on this day and the only degrees added to the angle of the Sun are those already added by our latitude. Cool, huh? And relatively easy. Later you will make some inferences about the tilt of the Earth from these same sun stick measurements.

On the next page is a diagram of the Earth-Sun-Tilt relationship. Imagine that you are looking at this three-dimensional system at a 45° angle above it and over a year’s time. Because it is a diagram, it is not a perfect representation. But we hope it will be helpful in illustrating the text.

> "Indeed, attention is not simply a virtue of intelligence or the result of education, and something one can easily do without. It is a state of being. It is a state without which we shall never be able to perfect ourselves. In its truest sense it is the listening post of the universe."
>
> — Jacques Lusseyran , *The Blind in Society*

A Diagram of the Earth-Sun Relationship

Notice that the Earth's tilt is always directed towards one place in space (in this model, it is towards the left. But notice all you need to do is move your perspective to underneath or some other side, and saying the pole tilts towards "the left" becomes meaningless. Something to keep in mind when you talk about how models are limited.) The Earth moves around the Sun during a year, changing the line-up between forward tilt and Sun, and hence causing the seasons. For example, when the Sun is on the same side as the forward tilt, the Northern Hemisphere has summer.



Kindergarten through Second Grade

Developmental Issues

This activity involves a shift in perspective to thinking about the world that we are standing on as something that is on the Earth in the form of a model. Then we need to envision ourselves and others as being on that model. This is a challenge for K-2. There is also very little chance students of this age group will be able to comprehend the large-scale measuring system of latitude. Nor will they be able to imagine the world cut up into bits according to their angle above the equator. So what to do? How are we going to link the idea of Sun shadow to Place on the Earth? We will put objects on the globe and see what shadows look like there. We will talk about why we think they look that way.

Inquiry Introduction

Does everybody in the world have shadows? How do you know? What if there were no lamps? Could they still have shadows? From what? They will talk about the Sun. Does everyone have sunlight? Why? Does everyone have a day and night? Yes, of course. But do they all have shadows like ours? Would they have had their flags in the same place as ours were if the tree were in their town? How could we try this?

Inquiry Investigation

Get a globe with no frame and put a bit of blue-tak on your town or close to it. Put a mini tree shape on this spot as if it were growing straight up out of the globe. Ask someone to pick a town somewhere else on the globe. Put another dab of blue-tak and another mini tree shape on this spot. Do this for a few more places (in good spots above and below the equator) and then turn on the overhead projector so that it is pointing at the globe.

Gather everyone around so that they can see the shadows cast by the little trees. Are the shadows the same or different? Turn the globe so that all of the places with trees get the light. Which shadows are the longest shadows? Which shadows are the shortest? Where do the shortest ones all seem to be? Around the middle of the globe. And the longest are all around the poles. Why? Move to the blackboard or a map with some blue-tak. Where do you think we could put trees on this world here so that they'd have different shadows? Let them stick trees on this flat object. Aim this towards the light as well, but at a slight angle (or no shadows, right?). Are any of these shadows on the paper different from each other? They will be the same length. Have them look at both the paper and the globe. What is the difference between these two worlds? One is flat the other is round, they will say. Which one is like our world? It is not important that they know the real answer, only that they keep thinking about it for a while as the year continues.

Where people are located on the Earth determines how much Sun they get in a day. Who do you think gets less Sun? They may want to think some about the coldness or hotness of a place. Which place is hotter, Florida or Alaska? Where are they on this globe? Who has longer shadows? Who has shorter shadows? How did we make long or short shadows when we were playing with the flashlights? They may recall that when they tipped the flashlight up or down, they could change the shadow lengths. Relate this to people living tipped up or down from the middle of the world.

> "What we call the beginning is often the end
> And to make an end is to make a beginning.
> The end is where we start from ...
> We shall not cease from exploration
> And the end of all our exploring
> Will be to arrive where we started
> And know the place for the first time."
>
> — T. S. Eliot

> "Mind boggling is a definition for 'astronomical.' As such, astronomy...can be a fascinating hook for grabbing and holding the attention of students to science. Not just those who will go into science, but all students, including those who become librarians, lawyers, doctors, politicians, and homemakers. They all need to know what science is about and why it is useful and important!"
>
> — David Crawford and Eric Crane

Second Grade through Fourth Grade

Developmental Issues

This activity involves a shift in perspective. We are going to use a model to represent the Sun, the Earth, and our place on the Earth. The children need to imagine that a globe is really the Earth, and they need to envision themselves and others as being on that model of the Earth. This is a challenge for 2-3. These students have acquired an intellectual capacity which allows them to think about more than one variable. They can think about where others are and even begin to think about things almost unrelated to their position - with some helpful concrete example to guide them. The modeling we did during *This is a Stickup!* allowed us to see our investigation as it would have looked from the sky. What we would like to think about in this Thread is what would it have looked like from some other person's school. Children at this age tend to form groups, so it should be easy to divide the class up into teams which will all pick a place they want to examine. Letting each team recreate the previous investigation, but this time for a town of their own choosing will satiate their desire for collective endeavors and their need to be given important tasks.

Inquiry Introduction

Does everyone in our world see the same sun stick shadows as we do? Would people somewhere else in the world see a difference between our sun stick drawings and their sun stick drawings? Why might they be different? Do they have the same day and night as we do? How could we examine this in the classroom?

Inquiry Investigation

Hang a globe from the ceiling, low enough to be reached easily, or hold one without a frame. Ask students where to put the Sun, or a strong bulb. Shine the light source at the globe. The light source must be large enough to illuminate the entire face of Earth. (While the Earth is actually tilted in its orbit, this is a complication which will not be dealt with just yet.)

The class should be divided into three or four groups. In each group, they should choose a place somewhere in the world other than their home town, maybe where they have family or friends. One group should locate their place on the hanging globe and help you place a small golf tee (head down) to the spot with blue-tak. You should place a tee at the school's location as well. What are the golf tees supposed to represent? Small versions of the sun stick!

How would we make the sun stick shadows on the globe? Students will say move the overhead projector or the globe. Which is easier? Answering this question may help us understand why the Sun's apparent movement is caused by the Earth spinning and why the Sun is not orbiting around the Earth instead—the Sun is large and much harder to move! Slowly turn the globe counter clockwise so that each tee "sees" the Sun rise in the east and set in the west. Is the pattern of shadow lines from the tees similar to the pattern cast by the sticks in the previous Threads? What are the differences between the golf tee shadows at the school's location on the globe and at the location picked by the first team? Why is this happening? Does the shape of our world make this happen?

Attach a third tee to the second team's spot on the globe. Slowly turn the globe again. Does the light reach this tee before or after it reaches the first team's tee or even the school's tee? So, does the Sun rise earlier or later in this new location? Are both team's tees always in light together or are both always in darkness together? Or can one be in light while the other is in darkness? What if the two tees were on opposite sides of the Earth?

Continue placing the other team's tees on the globe and asking the same questions. When they are all attached and examined, ask the students what they think is making the shadows shorter or longer? Which teams had the longest shadows? Where was this team's tee? What makes its location different than the other tees? Students should begin to articulate the differences, some unrelated and others crucial.

Ask students to remember how they were able to make longer or shorter shadows when they used flashlights. Tilt, yes—now your students may begin thinking about the tilt of the tees. However, it may not be very obvious that the curve of the globe is the same as the tilt of the tee. This is OK.

Ask them how they would move either the overhead projector or the globe to get shorter shadows. They will say lift the projector. Could you really lift that thing! Then what is another solution? You could tilt the globe. Select the school's tee so as not to appear to be favoring any single team, and tilt the globe. Ask the students to be watching the shadow lengths carefully. What happened when the globe tilted back? How short was the shadow?

Attach two more golf tees to the globe at various latitudes but along the school's meridian of longitude (so that you can keep your tee there for consistency). One should be on the equator and one should be near theNorth pole. It is not necessary at this juncture to call these positions by their map names. Face them into the overhead projector. What do the shadows look like for the different tees? Whose shadow is longest, the top, the school's, or the bottom? Why is this?

Viewing the globe from the side, can we see how the tees appear to be along a curve? Get a textbook and blue-tak three more golf tees to the front of it. Hold it next to the globe so that the tees are pointed straight at the light. What are the shadows like? There are none! What could we do to make some? Tilt the book? Tilt the book and have students look at the shadows. There are shadows now, but all three are the same length.

How do we know if we're spinning the globe in the right direction? Can they see the sun-stick shadows moving in the familiar direction? What is the shadow like at the equator? What about at your latitude? Ask the students what life is like at the different latitudes used. What are the trees like? The weather? The animals? What if the North Pole were pointed towards the Sun? Where would it be day and night? Would all locations still have both day and night?

> "The fascination of astronomy is a powerful tool for engaging the intellect and imagination of our youngsters, and this is what encourages us to make it part of the positive school experience of every child."
>
> — Andrew Fraknoi

> "The world of learning is so broad, and the human soul is so limited in power! We reach forth and strain every nerve, but we seize only a bit of the curtain that hides the infinite from us."
>
> — Maria Mitchell

> "The popular idea that a child forgets easily is not an accurate one. Many people go right through life in the grip of an idea which has been impressed on them in very tender years."
>
> — Agatha Christie

Fourth Grade through Sixth Grade

Developmental Issues

In this age group, big numbers, careful measuring, data collection, pattern finding and abstract problem solving are now possible. This Thread at its most complex is ideal for students of this age level. They will be guiding their own learning. The sun stick construction is by now old hat, and they will be comfortable about reconstructing it and taking data from it. Familiarity with the modeling will help them take their observations back into the classroom with their mental gears already searching for ways to talk about what they've seen in the different arenas of experience. By now, hopefully everyone understands that every way of talking about our observations is helpful. The use of the Internet can be an important part of this Thread, and these students have the dexterity and the skills to use it well. If you or someone you know does not have access to the Internet for collecting sunrise/sunset times, please request a packet of them from us. It is crucial here that teachers not do this investigation around an equinox. It will not demonstrate the situation it is intended to at that time.

Inquiry Introduction

What do sun stick measurements look like for people living elsewhere on the Earth? Are they the same? How? Well, the Sun probably rises and sets for all people, so they have shadows that seem to move during the day in time with the Sun. What might be different about sun stick shadows around the world? What is the shape of the world? Does this curving shape have any impact on the shadows or where the Sun appears to be during the day or year? Could the shape of the world also make a difference in the length of daylight time people get in different countries?

Inquiry Investigation

There is a good Internet site for sunrise and sunset times for almost any city in the world. If you do not have access to this Internet site, http://www.argonet.co.uk/location/works/sunrise/ssr.html, request the packet. Get sunrise and sunset times for today for your town or the capital of the state you are in (local paper will give you these). Write the times on the board, and ask the students how they would find out the total number of daylight hours from these times. This is not as easy as it looks, but the easiest way to do it is to think about the day in two parts: morning and afternoon. This is because the clock reaches its maximum value at twelve and then starts counting from one again. This makes it rough for adding or subtracting! However, taking twelve noon and subtracting the sunrise time tells you the number of morning light hours. The sunset time is always going to be a number which is equivalent to the number of hours past noon, hence "afternoon". So, adding the sunset time to the number of hours of light before noon gives you the total hours of daylight. They should, however, be able to come up with this on their own. But now you have the background information you need to nudge them a little towards the discovery. Give them time to play with the numbers and see what schemes they can devise.

Have every student choose a state capital or country somewhere in the world. If you are using the packet only, use capital cities of the United States, and encourage the choice of Hawaii, Alaska, and the Virgin Islands. Where is your city on a globe? Provide globes on every table or a big globe in the front of the class. Put little tabs on your city or at least mark it on a photocopy of a world map. Before you look up your city in the packet (or on the Internet), do you have any predictions about how long you think the daylight will last at your chosen location when compared to the length of daylight at the school for today? What is your reason? In their journals, have them write down their city and what country it is in. Suggest that they write down what they think about the length of day.

Give students the appropriate entry in the packet and explain to them how the packet is laid out. If you are using the Internet, let them take turns at the computer gathering data from the Internet site for their capital city. They should write their numbers down carefully somewhere or even print out the page from the computer screen. Keeping a table of the numbers would be best done by older students. Can each of us calculate the length of daylight for our chosen cities? When each student has a length of daylight for his or her city, begin your own table of daylight times, but with a row for each city and a column next to this for the length of day. And later, when it is realized that the latitude is linked to the length of the day, add one more column for the latitude.

Going around the room, have each student call out his city and the length of day he calculated for it. Write this in the table. After a few cities are discussed, the students will definitely notice there is a difference in the lengths of day. Locate on the globe the first few cities that have been mentioned. Does anyone see why these places might have different amounts of sunlight during the day? They will list those things which are different about where each city is. But the question is, of course, why should those differences have any influence over the sunlight? Gather more cities and find them on the globe. Which cities have the shortest amount of daylight? Where are they? Which have the most amount of sunlight during the day? Where are these cities? If you have cities in both the southern and northern hemispheres, there will be a definite pattern of average daylight time for cities nearer the middle of the globe and longer days for cities on one half of the globe only. The cities on the other half will have shorter days. What is happening?

Place small blobs of blue-tak with toothpicks of equal length on a few of the labeled cities which have the greatest differences in daylight times. Shine a very bright overhead projector or lamp onto the globe and hit those cities. Can everyone see the shadow lengths of the toothpicks at these different cities? Is there a pattern? Is there any connection between the daylight time and the sun stick lengths? What might be the situation here? It may be necessary to step back and think about what it looks like to do the sun stick measurement.

What does the shape of the world look like outside? Does it look like a sphere out there? No, it looks rather flat! Let's try to create flat areas for our cities here. Get a small square of stiff paper like manila or oaktag paper. Put the paper under one of the cities so that it lies flat on the point where the city blue-tak is and creates a tangent plane at that point. (A tangent plane is a plane touching only one point along the surface area defined by a sphere.) Then make another for the other cities. Are these flat views the same as each other? No, but they are what each person sees at that spot, flatness. What is the difference between the flat areas? How do you have to move your head to be flat with them? There is a tilt of some kind here. Does that change where the Sun appears in the sky? If it is not painful for the eye, have students come up and move their heads so that they are flat with the city and then look at the light source chosen to be the Sun. How high does it look compared to the background of the classroom? The higher you tilt on the globe, the lower the Sun appears. Do you think that people who see the Sun very low have more or less sunlight during the day? Less. Where are those places on the globe? What were the daylight times for those cities?

There will still be confusion regarding the strangeness of how the two halves of the Earth have the greatest difference in daylight time. Ask them directly what would happen to the shadows if you tilted the globe even more in one direction? In some places, the Sun will seem higher, and in other places, lower. Discuss this until the students can understand the changing perspective.

Is there a good way of dividing the globe into pieces that we could talk about more easily than saying, "Well, at the location of Tokyo …" How do we give locations of cities anyway? Students will call out the latitude and longitude idea. Can they point out on which latitude lines the various cities on the map lie? Why is the equator zero? What does zero mean? Why isn't zero at the top or bottom? And why are the latitudes in degrees?

Thinking about this convention might be difficult. When we did the sun stick triangles, we used the flat line of the shadow on the ground as the bottom of the triangle and said the Sun's height, measured in degrees, was the size of the angle — also measured in degrees — made when a line drawn from the position of the Sun meets the shadow line on the ground. But where on Earth would you start from, where would "zero" be? Where on the Earth would the Sun, at mid-day, be most likely to cast "zero" shadow? In other words, where are you most likely to find the Sun directly overhead? At the equator, the line drawn around the middle of the Earth which divides the Earth into two equal parts. If you take a line drawn from the equator to the center of the Earth as having an angle of 0 degrees, then you can measure the latitude of any place on Earth above or below the equator by measuring the angle between a line drawn from that spot to the center of the Earth and a line drawn to the center from the equator.

Hold a globe to the blackboard and have someone help you trace the outline of the globe on the board. Draw a careful line in the middle of the circle on the board. What is this? The equator, of course. Mark the center of the circle on the board. Using protractors fixed on the center point, can the students mark lines along the circle where 20° and 40° etc. all hit? When these marks are made, extend them out longer to the globe circle, so that they will be clearly visible. Draw horizontal lines across the globe which hit these marks on the edges of the circle. Then hold the globe back on the board over the trace and see if the marks match those corresponding latitude lines on the globe. Bingo! That is how all this is works.

Can a latitude line give us the exact location of a city on the globe? If you say the city is at 42° north latitude, how many cities are also on this latitude? What else do we need?

What about those longitude lines? Look down on the top of the globe. There are rays coming out of the North pole as well. The same exercise could work here, however, the longitude conventions use an 180° basis instead of the 90° basis used by the latitude system. But the idea is the same: rays made from angles drawn around a circle. So, how could you classify two cities such as Beijing, China and Denver, Colorado? Then try Oslo, Norway and Pittsburgh, PA?

If we didn't have a globe, how could we figure out our latitude? There are two good ways, one involving the North Pole star and the other using those sun-stick measurements. Obviously, in the classroom, there is only one we can use easily. But we'll include information about the other one, so that students can do it at home.

Using the equinox data collected by you or your class, follow the procedures for finding the height of the Sun in degrees outlined in This is a Stickup! OK, so we've got some angles measuring the Sun's height. What can we do to think more about how this relates to the whole world?

Ask the students about their *Stickup* set-up. What did it look like? Draw on the board the stick and a shadow coming off to the right. Where is the sunlight coming from? They should be able to tell you that there is sunlight coming over the stick. Draw rays coming over the stick and hitting the stick or going over it to make the shadow. Draw this carefully so that the rays hit the stick and we can tell where the shadow will be by making that last set of rays skim over the top of the stick and mark the end of the shadow.

Are the lines straight? Is this what was happening at our set-ups? Does this look confusing? Do we need all of these sun rays? Which ones are the most important to think about here? Erase all of the rays except the one that points directly from the top of the stick to the Sun. What is the shape being made by the lines of sun stick, shadow, and sunlight line? Students should be able to tell you this from their experiences with the previous Thread that it is a triangle. But can they tell you what this would look like from outer space? Please refer to the diagram at the end of this Thread for help recreating it on your board.

Where is the angle that marks the height of the Sun? They will point to the end of the shadow and how it can be linked to the top of the stick and then back to the Sun. Good.

On the board, draw a large circle to represent the Earth with a line through the middle and extend the line out from the circle quite a bit. What special mark on the Earth is this? That is the equator. Draw a short line sticking straight out of the side of the circle (about at your latitude, basically), somewhere above the equator line. Imagine this is the stick we stuck in a can. Connect the stick line to the center of the world with a dotted line so that we can think about where the stick is with relation to where the equator is. What does that angle made by the Equator and the stick line mean about where the stick is on the Earth? It means it is the same number of degrees above the middle, or equator, which is the same as saying it is at that latitude. Do we see that? Take another look at the drawing at the end of this section, if this is not clear. Let's mark a dark **L** in the angle; L for latitude. Cool.

Where is the Sun? Many will point off to the side somewhere. Draw a circle there. Is the Sun this small? Is it this close to the world? Maybe we should make it bigger and move it further away. Use the whole side edge of the blackboard as the Sun's edge and draw lines of sunlight coming from this edge to the world. The lines should be straight and parallel to the Equator line. This allows us to see that the rays are very straight when they hit the world and the stick.

What can we notice now about this ray and the line of the Equator? They are parallel, or flat with each other. What about the stick? Its extension crosses both the lines. Let's try to zoom in here.

Below the big world drawing, simplify the diagram by drawing two parallel lines crossed by another line like the stick line. Label them like they are labeled in the world drawing, including marking where L is. Does everyone agree that the lines you've just drawn are really a simpler version of the drawing above them? This is a math drawing, and it will help us to talk more easily about triangles.

Do any of these other angles look like **L**? It is difficult to see. How could we check it out? Make a right triangle out of heavy paper so that it fits perfectly into this L angle and is big enough to be seen across the room. In other words, make a triangle with one angle 90° and another angle L°. Mark L at the L angle and on the other side of the triangle as well. Where does this fit into our drawing? Where else might we be able to fit this triangle in the picture? Have students come up to the board and try to fit the triangle into some place of their choosing. They will find that it fits into the space made by the stick's end and the ray of sunlight. Flip the triangle over. Is this angle **L** the same as it was before? Yes. It can't be different because the triangle did not change. This is like flipping shapes from *Guess My Shape*. The shape can look different even if it does not change but is only flipped or rotated. In the drawing provided, the shaded area shows that this is indeed the same triangle.

They will then find that the triangle shape fits into all angles directly across from the L one. Great. This means something important. This means that the angle of the latitude is the same as the angle made by the Sun line and the top end of the sun-stick. But in *This is a Stickup*, we only measured the angle of the shadow line and the ground, and not the angle of the stick and the ray of sunlight, which we now know as **L**. How could we ever find **L**?

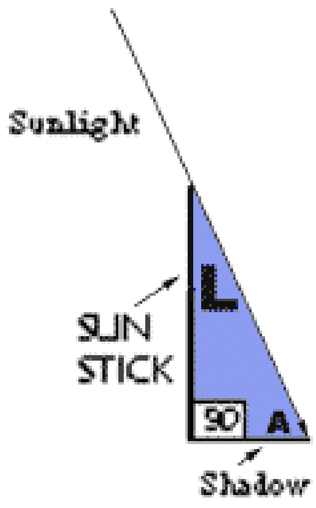
What is the angle made by the sun stick and the ground for every sun-stick measurement? Was the stick straight up? Straight up means what angle? Can everyone find straight up with a protractor? What is the angle? 90°. OK. So, now we know two of the angles in the triangle: we know the one we measured at the shadow and the ray of sunlight and we know about the 90° made by the stick and the ground. What is the other angle, **L**? Does anyone suggest just looking up our latitude in the atlas? Why not? Does anyone think we can really discover it ourselves? Nah, that's what scientists do or something, right?

Hand out paper right triangles of different side lengths. Have teams measure each angle in each triangle. Add the three angle values together. What is the total of each team's triangle? 180° always. So here's a clue. If we know two out of three angles of a triangle, we can find the third angle. How? Let them puzzle this for a while, and then if they can't come up with the solution, ask them to add up the angles they do know. How much of the total do they have? Is that 180°? How much more until they can get 180°, or in other words, what is 180° minus their sum? Tah-dah!

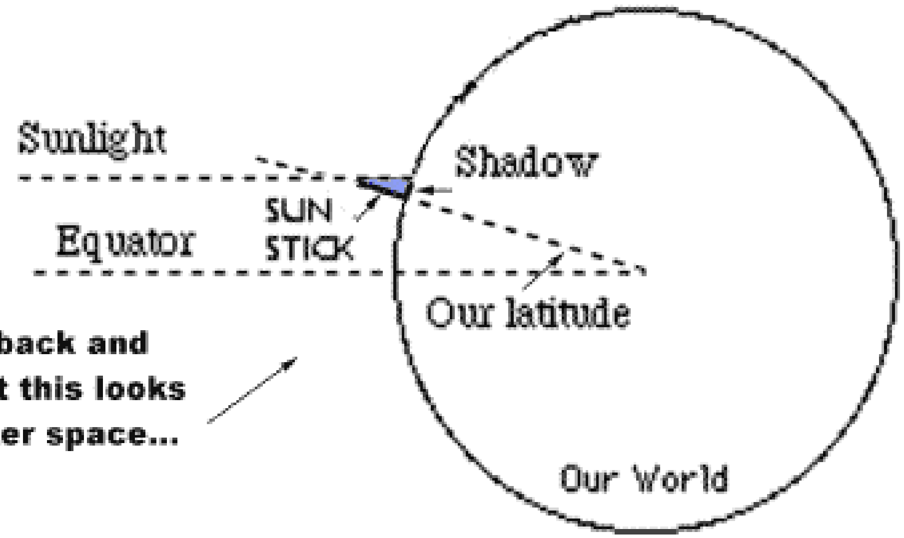
Back to the sunstick problem. What was the angle of the stick with the ground? 90°. Write this into the sunstick triangle drawing. What is the angle of the Sun's height at midday on the equinox, (that is the angle of the shadow tip and the ray of sunlight)? We will have to look at our data from *Stickup* to get this value; we have three different ways of finding it, remember? Write this angle in the drawing as well. Add them together. What is the third angle, or what is 180° minus our sum? Write it in the sunstick triangle and then move it over to the corresponding place on the simpler parallel line drawing. Which angle is like this missing angle? That is angle **L**! It must be our latitude. How do we know if we are right? Who looked it up earlier? How did we do? We rule.

Now for some predictions. What would happen to the shadow lengths if the Sun moved up or down? Or if the Earth somehow tilted over and back? Do you think these things happen? If we take length of daylight and shadow length measurements every week for the school year, do you predict we will we see anything change?

Our Data



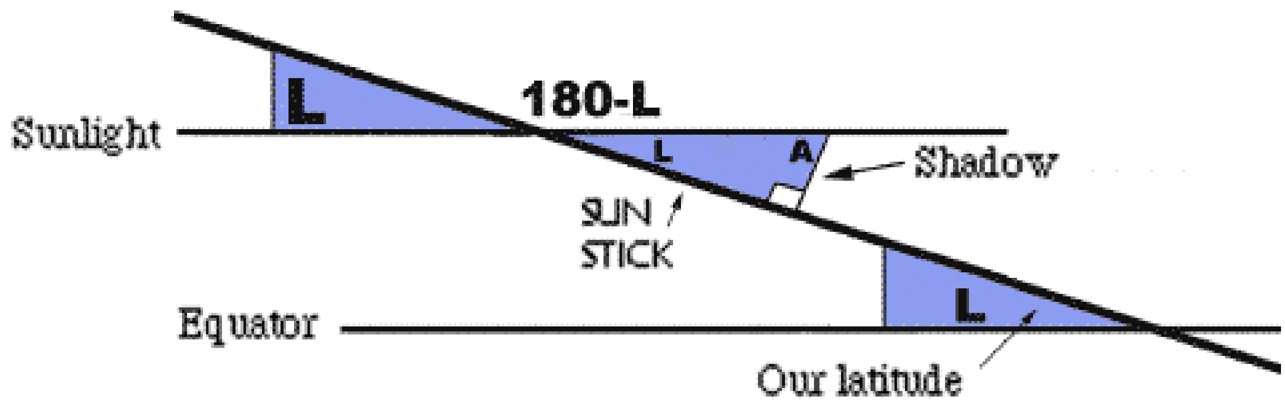
A Model



Let's step back and imagine what this looks like from outer space...

Let's translate this drawing to a math diagram...

The Math



When two parallel lines, like Sunlight and Equator, are crossed by another line, like Sun Stick, it is true that all opposite angles are the same. This means that the angle L made from the Sunlight hitting the stick is the same angle as the latitude of the town the stick is in.

Time Warp

Purpose

We will think more about time and the Sun and the shape of the Earth. It is important to realize that the Sun does not rise at the same moment in different places and that clocks around the world are set to their "local" time. The National Science Education Standards require that the motion of the Earth be linked to the changes on it, such as length of day. The vocabulary words which can be integrated in this Thread are time, clock, time zones, orbit, and international date line.

Teacher Background

It used to be common for each city to keep its own time according to the position of the Sun in the sky. Long train rides, particularly easterly and westerly trips, often required travelers to change their watches several times. What a pain. Eventually it was arranged that the globe would be simply divided into vertical chunks according to the country and local desires, keeping uniform time within each chunk. This is why the time zone map looks much different from the actual longitude map. We've included a convenient map here to help visualize what we're talking about.

You will need: globes, clocks, overhead projectors, blue-tak, golf tees (younger grades can use their toothpick trees).

You may want to spend some class periods on this subject, as the idea of time really can be extended to many other lessons you may want to do. The early grades especially learn how to read clocks and tell time, so you may want to slip this Thread somewhere into your other lessons after your class has had a chance to think more about time keeping. Other grades may want to build different types of clocks to think more about accuracy. At the end of this Thread is a page of supplementary clock-making activities. Materials collection can be very brief or extensive, especially if you use the extra clock activities.

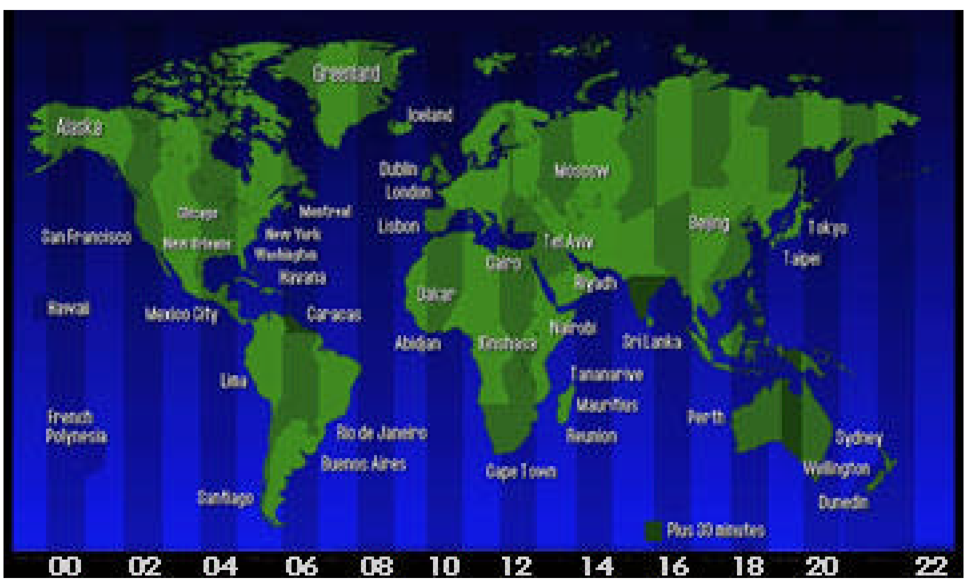
From a scientific point of view, of course, it would be far more logical to have divided the world up into 24 equal parts, one part for each hour of the day. With the circumference (distance around a sphere) of the world being about 24,000 miles, this would divide quite nicely into 1000 miles around the equator for every hour. So, if you knew the distance from here to Tokyo, you could find the local time there. Or could you? Which way would you measure from?

Thinking about the rising of the Sun is thinking about time. Which way does the world spin to make the Sun appear to rise in the east? The world must spin towards the east, so that we spin towards, past, and away from the Sun to make a day happen. This would mean that people further east of us will spin towards the Sun before we reach the same point, we being a little further back from them along the curve. So, to find out what time it is in Tokyo, you should think about that and the fact that the starting point (International Date Line) was decided to be somewhere in the Pacific Ocean.

So, is it later or earlier in Tokyo from where you are? If you are in Boston, it is later in the day for Tokyo because they have had more Sun time than you have. If you are in New Zealand, it is earlier in the day for Tokyo because they have had less Sun time than you have. On a globe, if you live more to the east, (to your right, so long as the North pole is “up”) than the place you want to know about, then you have had more day than they have. Just be careful about which side of the International Date Line you fall!

However, this 24 hour/1000 mile system is all well and good only for a uniformly populated world and from a scientific point of view. Time zones proper come from the desire of governments to limit the confusion which would result from too much watch changing among the ever mobile populations of their countries For example, although the contiguous United States spans one-fourth of the circumference of the world, it only has four time zones when it really might have had six.

This map was taken from: http://www.telkom.co.za/time_zone_map.htm



Kindergarten through Second Grade

Developmental Issues

It will be very hard to talk about time zones, since math and abstract perspectives need to be utilized to really understand the time zones. Therefore, what we will do for this age group is use the globe to see the Sun shadows through the day. We will try to link these with time.

The big understanding for this group is: "If people live pretty close to you, then it's dark for them when it's dark for you. If they live far away, it could be dark outside when it is light for you and vice versa."

Inquiry Introduction

With the globe set-up from the last Investigation, *Latitudes and Attitudes*, let's direct our questioning to a different idea. Which tee on the globe gets to make a shadow first? What does that mean about which people get to see the Sun first? Are they the same? Then how long do we have to wait for morning to come? Could we actually have a friend who wakes up half a day earlier than we do because she has morning half a day before us?

Inquiry Investigation

Play with the globe, turning it in front of the light. Have the students place the golf tees where morning would arrive first. Trick them by turning the globe and then having them try again. There has to be some place on the globe where we start, some place where we all measure morning from. Point out the International Date Line on the globe, and have them try this all again.

Where is our home? Where are family members or friends? Where is it night? Where is it day? What is a time of day which is daytime, 10 p.m.? Maybe more like 9 AM. If we are having morning at 9 a.m., should everyone in the world call it 9 AM? Maybe they should call their morning time 9 a.m.

What does that mean about time? Is there anything that is always keeping time going, without a battery or electricity? Something we could watch and know roughly the time? Can we all have the same clock? Or do we need to change it depending on where we live? Wouldn't that be a bother? In what ways do we rely upon time for things we do everyday? How could we all tell time without the clock or the Sun?

Second Grade through Fourth Grade

Developmental Issues

This age group is becoming familiar with the idea of time and future, and can also use numbers to think about things. They are also capable of thinking about others' points of view. Therefore, we will use the globes and talk about time as it relates to a spinning Earth. This age group would enjoy making the sand or water clocks.

Inquiry Introduction

How many hours are there in a day? Why? What is an hour? Who decided about that? Or about minutes or seconds? Why sixty seconds in a minute? Why not 50 or 100? That would be much easier to understand and think about. What is happening in those 24 hours? What is moving and can we watch it happen? Do you recall the Sun's movement across the sky? The Sun appears to move once around the Earth in those 24 hours.

Inquiry Investigation

Reconstruct or grab the globe with the golf tees on it. We learned about the Sun height here in relation to where you live on the curved world. What about the sunrise? Shine the overhead lamp on the globe again. Spin the globe and ask the students which tee is getting the Sun first? Who is having dinner or sleeping when this tee is having lunch? What happens if you call a friend at 9 a.m. and she lives far around the world? Is it 9 a.m. for her? What is her time? Why? Would it be hard to have everyone using one clock? We could never talk about morning being 9 a.m. because it isn't morning for your friend over there, is it? What might we do to straighten this out? What could we think about that has to do with clocks which could help us here?

Thinking some more about time, it seems that the Sun really tells us much about time in our lives. We rely on it to govern how long a day is, right? What is a day? It is the time it takes for the Sun to appear to go all around the world, or in other words, the time it takes the world to spin once. But those hour things are man-made. Could we use a day to think more about longer lengths of time?

What other periods of time are there that do not rely so heavily on made-up time frames like hours? Suggest that they think about going around in a circle around the Sun. How many days does that take? Does the length of time the Earth takes to spin us past the Sun rely upon someone else's definition of something? Since a day is usually measured by these things called hours, while a year is measured by definite cycles called days, could 365 days be a good unit of time measurement? If a day is an Earth-turn time, a year is an Earth-orbit time. Play more with globes and this new idea. Students ready to play with some math ideas here could manipulate the globe and try to divide it up in easy ways. Or check out the math activities in the next level of this Thread.

Developmental Issues

Let's use some simple subtraction and division to think about dividing the world up into time zones. It would be good to approach this subject from that angle, because geometry plays such an important role in thinking about our world — the more we use it, the better we will feel about using it more!

Inquiry Introduction

Where does the Sun rise for the different towns around the world? What about for those cities we have chosen to think about. Why doesn't it say that the Sun rises at 5 p.m. for them? Can the Sun possibly rise for them at the very same moment it does for us? What is time, then? Who determines the time for a certain place?

Ask the students how they think they might solve this problem. Could we find a way so that everyone could have a time and it would be right? Would it be useful for *everyone* in the world to say it was noon when the Sun was only overhead at *one* place on the Earth? About a century ago, this problem was addressed at an international meeting and twenty-four standard time zones were adopted. Why were there 24 time zones made? Hopefully, students will link these 24 zones with the 24 hours that make up one day.

Inquiry Investigation

Can we divide the globe into 24 zones? How do you see 24 zones, and in which way should the globe be divided so that the pieces are related to the Sun's movement? Ask them whether or not this makes sense given our understanding of time. If all the clocks in a given time zone are set to the same time, by how much do adjacent time zones differ? This is good practice for learning to use numbers in a practical fashion. What time is it two time zones away to the west of us? This is a trickier question. With the globe and light source, can the students prove their answers? Can everyone see that the world to the west is having sunrise later and therefore their clocks are behind those in the world to the east? Do they now find a different answer for which 24 pieces they would divide the globe into? Each time zone is centered about a line of longitude, or meridian.

How far across the sky does the Sun appear to go during daylight time? They will say all the way across, or halfway around the Earth. Ask them what that amount could be called instead of “all of the way” or “halfway”. How many fists do we need to cover the arc of the sky? Does anyone recall how many degrees a fist covers? It is roughly 10°. How many degrees are in a circle? How many degrees are in half of a circle, then? They will find that it takes around 18 fists or so to measure from one horizon up and over to the other. How many more fists would you need to cover the sky seen by people on the other side of the Earth? Find out from them if they think they could use math to find that answer easier than trying to measure it.

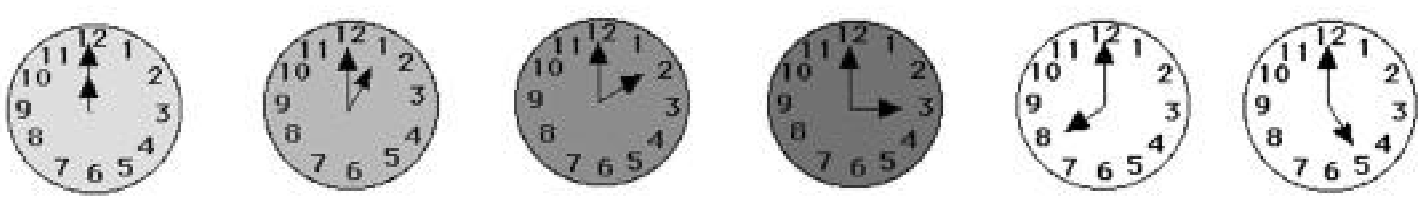
Since it takes twenty-four hours for the Earth to spin (or for the Sun to pass over all of the Earth), how many fists can the Sun travel through in only one hour? Remind the students that in 24 hours, the Sun has to travel through 36 fists. So the real mystery is solved by a little math. How many fists do we need to measure one hour? The math is of course 36 fists ÷ 24 fists which is 3÷2, 1.5 fists, or one and one half fists. How many degrees are in one fist? So, how many degrees does the Sun seem to travel in one hour across the sky? 15 °. Going backwards, saying if the Sun can travel 15° in one hour, how many degrees can the Sun travel in 24 hours? 360° of course, since 15° in one hour times 24 hours = 360°. That is how many degrees there are in a circle.

So, then ask your students this: If the globe is divided up into 24 time zones, how many degrees wide is each time zone? They should then conclude that the time width of each time zone is one hour, so the number of degrees in this zone is 15 in longitude.

The establishment of standard time zones is intimately linked with the establishment of the standard grid of latitude and longitude. Ask students: if it is 7 P.M. in Boston, where is it midnight? Midnight is 12 o'clock. 12 minus 7 is 5. Whoever is having midnight is five time zones away. They will hopefully count ahead to the east on the globe 5 slots to rest on England. Ask them what day it is at that point. Do they think that they would be time traveling if they flew westward to this point?

Using a globe, have the students locate the United States. There are four time zones in North America: Eastern, Central, Mountain and Pacific. Can they discern how many degrees there must be across the country's mainland from the number of time zones across it? Think if there are 24 hours in a day, there should be 24 time zones. 24 goes into 360 degrees 15 times. So, each time zone should be approximately 15 degrees across, making the United States 15 degrees times 4 across the globe, or 60 degrees. Check this with the latitude measures on the globe. You will have to account for fractions. What do we notice about how regular or irregular the real time zones are? Why might this be so? Think about politics and the shapes of states.

Students should already understand that different locations on the globe experience day and night at different times. Even so, the whole notion of time zones may seem a bit mysterious at first glance. Can we find the local times for our relatives around the country right now? What about for areas in the news? Which city on the Earth will yell, "Happy new year!" first? Can students begin to think of locations in terms of both time zones and longitude lines?



Los Angeles, California 12 Noon Jan 1 | Phoenix, Arizona 1 PM Jan 1 | Dallas, Texas 2 PM, Jan 1 | Boston, Massachusetts 3 PM, Jan 1 | London, England 8 PM, Jan 1 | Tokyo, Japan 5 AM, Jan 2

Tilt-A-World

Purpose

According to the National Science Education Standards, children should know how much the Earth tilts on its axis of rotation. We'd like to make this more of a logical discovery from their experiences than one of those facts they are forced to learn for the sake of "science" tests. It has been shown that most adults do not retain this information from their primary school memorization, so this Thread will try a different route to really learning and understanding this fact about our world. Vocabulary words which can be integrated into this Thread are tilt, seasons, clockwise, counter clockwise, equinox, solstice, and year.

Teacher Background

This repeats some of the Teacher Background from *Latitudes and Attitudes*. Most of the planets in our Solar System are tilted over on their spin axes. We are not sure why this is so, perhaps it is due to the violent collisions common in the early Solar System when there were thousands of small rogue planets circling the Sun. The Earth tilts over on its axis 23.5° with respect to the axis of the Solar System. This means that the Earth is always "pointing" to one side as it goes around the Sun. So, sometimes the Sun is in the direction that the Earth is pointing, but not at other times.

You will need: set-ups from Latitudes and Attitudes, Internet WWW browser with graphics if possible, paper and pencils.

There is not much time required here to gather materials, since this Thread reuses those from before. You will probably also only need a few class periods to explore this topic and any other related subjects you include. Teachers of higher grades may want to spend more time on this for the geometry opportunities it provides.

The effect the tilt has on the Earth is that at some times during the year, Earth's orbit makes the northern hemisphere tilt towards the heat and light of the Sun. The increased height of the Sun above the horizon lengthens the length of time this part of Earth receives daylight as well as the intensity of the light (remember the *Me and My Shadow* flashlight investigation). This increases the amount of light this area of the world gets, thus the overall temperature there increases, since more time in the light means less time for the land and air to cool down before being lit and hence warmed again. In contrast, at the same time, the southern part of the Earth is receiving less daylight time and less intense light and thus is colder. In the southern hemisphere, they will always have Winter when the north is having Summer, and vice versa.

Spring and Fall however are perhaps the most interesting times of the year from an astronomical point of view. The tilt of the Earth is not directed towards or away from the Sun, so it could be said that these seasons are more like what the planet's weather would be like if the Earth did not tilt at all. This also means that if we have some data from the very middle of either the Spring or Fall seasons and also from the very middle of Summer, we could make a comparison between the amount of sunlight and the tilt of the Earth.

"Science moves with the spirit of an adventure characterized both by youthful arrogance and by the belief that the truth, once found, would be simple as well as pretty."

—James Watson

"The true scientist never loses the faculty of amusement. It is the essence of his being."

—J. Robert Oppenheimer

"The first precept was never to accept a thing as true until I knew it as such without a single doubt."

—Rene Descartes

Kindergarten through Second Grade

Developmental Issues

For this age group, this is a good time to go back and think about seasons, and shadows. Playing with the little trees again (after you've finished another installment of a Winter version of the sun stick investigation when the shadows are longer) will provide experiences to support understandings children develop in later grades.

It does not make sense to focus directly on the Earth's tilt with this age group. It is too difficult because it requires thinking about models and thinking hypothetically at the same time. It entails a big cognitive load to reason that the Earth must be tipped because it explains all of that data. This introduces a dilemma. You could just tell your students and then have them see how the explanation fits the data. That would be a good way to handle it but then, the answer you give makes it less likely that older students will actually go back and consider the question in earnest in future years. What to do? Think more about the seasons and our shadows.

Inquiry Introduction

Why when we were outside did things change so drastically? What is happening out there? Why do we have seasons? Why can't it be nice and warm all of the year? What is happening on our world? Why does it get cold? What happened to our shadows of the tree? Why could they get longer? Did the tree grow that much bigger in just a few months? What could have happened if the tree didn't move?

Inquiry Investigation

Get that globe with the blue-tak and little tree. Aim the lit overhead projector towards the globe. How could we make those shadows of the tree get longer? How did we play with flashlights to make longer shadows? We tilted the flashlights. Does the big Sun tilt itself every year? How can you tilt something that is light all over the place? What else could you tilt? Did the tree tilt? Maybe the world tilted?

Tilt the globe a little away from the overhead projector. What happened to the shadows? They got longer. Is that like what happened to the shadows of our tree? Could they get shorter again? How could we check that this had happened? Go back outside to see at some other time. How long might it take before those shadows get longer again? Let's go out then in about four months.

Is the world really tilting like that? Wouldn't we feel it if it did that all of a sudden? "Maybe it tilts slowly," someone might say. What might cause this? Let's try to think of why the world might do this, or if it really could.

Second Grade through Fourth Grade

Developmental Issues

Thinking about this tilted world system is possible in these grades, but must be approached concretely and in lots of different ways. Making some teams to play with globes and lights will help them to grow into this idea from experiences. The upper grades will come to studying the tilt with the benefit of some math to use as a means of additional experiences. But for this age level, we will mostly rely on what we've learned about how light and angles work together. Students in this age group can grasp these variables when approached from a hands-on experience.

Inquiry Introduction

The seasons are rapidly changing outside in our world – is there anything we can do about it? Nope. We are living on a world that is changing. But what is causing these changes? Is it a sudden thing? How often does it happen? This kind of thing has been happening forever, every year. What happens in one year to the world? The world moves once around the Sun in one year. Is there something that happens to it at different points on its trip that causes the seasons?

What might make it warmer? Many will say getting closer to the Sun would warm things up. Does that mean Summer happens when we are closer to the Sun? So, does the whole world have Summer when the Earth gets closer to the Sun? Some will then shake their heads because somewhere they know that other places are having Winter when we are having Summer. Oops.

Inquiry Investigation

Find those places on the world that we looked at in Latitudes and Attitudes. Check to see how many of those have live camera Web sites from the list on page 84. Ask the class: What season are we in now and what does that look like? If we could see these other places right now, we should look for those signs of the season there. If they are not there, what might that mean about the season? If you don't have access to the Internet, move on to the next page.

If you are in the Northern Hemisphere, places like South Africa provide awesome displays of this difference. If it is presently Winter for you, why are there flowers and green trees in South Africa? Look at more sites which are in the opposite hemisphere from yours as well as sites in your same hemisphere, without mentioning the term "hemispheres" just yet. What is the pattern here? Are there specific portions of the world where everyone seems to be having the same seasons we are, while others are experiencing the opposite season? What is the biggest pattern: our top half of the world has one season, but the other half does not. How can that happen?

Aim the overhead projector at the globe. How does the light hit the world? Use the example from above and consider: Is there much difference between how it hits us and how it hits Australia? Is it possible for these people to have a different season than we are having with the world like that? Could we move the globe around to try it out? Is it possible to make only one half of the world get warmer than the other? They may see where this is going, and say tilt the one half away or towards the light to make it warmer. If they don't, tilt it yourself and ask them what would happen if the Earth were tilted like this. How warm could this bit get as compared to the other bit?

But how does this change during the whole year? What does the world do in a year? It goes around the Sun. Does it wiggle back and forth as it goes? What would that be like? What if it just went so that sometimes it was flopped over towards the Sun and sometimes not?

Have a student be the Sun in the middle of a space in the room. Walk around her with the tilted Earth and stop at a point where your hemisphere is pointing toward the Sun. What season is this for us here? Summer. Move counter-clockwise 90° around the Sun person. What about here? It is Autumn or Fall. Keep going around another 90°: what about here? Winter – see our half is pointing away from the Sun. Move to the Spring space and ask again. Spring is here, and then on to...Summer.

> "We especially need imagination in science. It is not all mathematics, nor all logic, but it is somewhat beauty and poetry."
> —Maria Mitchell

> "To learn something new, take the path that you took yesterday."
> —John Burroughs

Fourth Grade through Sixth Grade

Developmental Issues

We don't need to sneak up on the subject for this age group. Doubtless they've already been told somewhere that the world is tilted, but it is unlikely that they could demonstrate, using their own experience, how the tilt works through the year. They will want to make the world wiggle over on one side and then the other. So, we should combine the measurement data collected from the Equinox and Solstice versions of the sun stick data.

Inquiry Introduction

What causes the seasons? Most will say that the tilting of the Earth is the cause. Does this tilt change during the year, then, in order to change the seasons? Is there any other way to make the seasons happen without the changing tilt?

Inquiry Investigation

Stick those golf tees on some towns used from Latitudes and Attitudes. Shine the overhead projector on the globe. What do the shadows of the tees look like? How do we make them longer or shorter? Tilt the globe one way or the other. What does that mean about the light that hits the globe? Look at the intensity of the light on the tilted part versus the non-tilted part. What does it look like? Would it be warmer or colder there? How does this pattern change during the year? How does the Earth orbit the Sun?

Have a student be the Sun and stand in the middle of a space in the room. Walk around her with a tilted Earth globe. Remember to aim your tilt at a point on the wall so that you keep the tilt direction always still, even if the Earth is moving around the Sun. A look back to the diagram in Latitudes and Attitudes might be good for preparing your role in this activity. Stop at a point where your hemisphere is pointing at the Sun. What season is this for us here? Summer. How long is the Sun out? Do you think the daylight time might be shorter or longer with that much Sun? When does the longest daylight time of the year occur? Why? And what is the temperature at this time of year?

Move counter-clockwise 90° around the Sun person. There is a drawing to help you within this Thread. What about here? It is Autumn or Fall. Are we tilted towards or away from the Sun? Would that cause any significant change in the temperature here? The tilt must be towards or away from the Sun in order to make a season with extreme temperatures like Winter or Summer. If the Earth had no tilt at all, life on the Earth would be very much like having Autumn all of the time. Is there any other season that might also not have a tilt towards or away from the Sun? It is Spring! How long might daylight time last during these seasons? Since there is no tilt factored into the Sun height, and the Sun is aimed at the middle of the Earth, it may be that the daylight time is in the middle, or half of 24 hours. It is a thought. Keep going around another 90°: What about here? Winter – see our half is pointing away from the Sun. How long are the days here? How long are the shadows here? When does the shortest day of the year occur? And what is the temperature at this time of year? How many days are in between the Summer and Winter times? How far around the Sun has the Earth traveled? The Earth has traveled to the opposite point of its orbit around the Sun. This is why the tilt seems to be “aimed” in exactly the opposite direction. The tilt didn’t wobble and the Sun didn’t really move—the Earth orbited around to a position where the tilt direction was now pointed away from the Sun. Move to the Spring space and ask again. Spring is here, and is there a tilt away or towards the Sun? So what can we say about this time? And then move on to...Summer again.

What do we all mean by Summer, then? Is it global Summer? No, it is hemispherical Summer. We should be careful to make sure we are certain which hemisphere we mean when we talk about Summer! So, when it is Summer for the U.S., for example, our part of the Earth is tilted towards the Sun. How might that change the Sun's apparent height in the sky for us? Would it seem higher or lower if we tilted back from it? Try rocking forward or backward in your chair while looking at a circle on the board. How high does it seem when you lean forward? Backward? It seems to sink when you lean back. So, a lower Sun in Winter. What would happen then to the shadows of trees if the Sun were more low in the sky?

Shine the overhead on the globe again. Repeat the seasons demonstration with the student standing in the middle of the room as the Sun. What are the shadows like for tees or people in different places? Shadows are lengthening for people as their "Winter" begins. Cool. We've been measuring shadow stick lengths throughout the year and can probably see the same thing in our data. And what do the shadow lengths tell us about the height of the Sun? In turn, what does the height of the Sun tell us about the amount of the Earth’s tilt in the Sun’s direction?

How much does the Earth really tilt? How could we ever find out? The longest day of the year happens when the Earth's northern part is directly aimed at the Sun and the shortest day is when the Earth's northern part is directly aimed away from the Sun. These longest and shortest days are when the tilt of the Earth is at its most extreme orientations with respect to the Sun. Don’t forget, at the equinoxes, there is no tilt factoring into the Sun height because the tilt direction is pointed perpendicular or 90° to the line between the Earth and the Sun. Can these facts help us find the degrees of the Earth’s tilt?

What was the height of the Sun at mid-day on the Winter solstice? What about on the Autumn or Spring equinox? What is the difference in height of the Sun between the equinox and the next solstice in fists or in true angles? If you have managed to get measurements for both equinoxes, brilliant! What is the difference between the solstice and the other equinox? They will be able to see that the difference is always around 23.5 degrees no matter what. The accuracy of their findings will depend upon how carefully they made their measurements.

Twenty three and a half degrees is the tilt of the Earth with respect to the flat orbit it makes around the Sun. They can check this number in a book or on the Internet if they choose, but now they know exactly how to find it again, just by using their own observations and data.

Find those places on the world that we looked at in Latitudes and Attitudes. If you have Internet access, check to see how many of those have live camera Web sites from the list on page 84. Ask the class: What season are we in now and what does that look like? If we could see these other places right now, we should look for those signs of the season there. If they are not there, what might that mean about the season?

If you are in the Northern Hemisphere, places like South Africa provide awesome displays of this difference. If it is presently Winter for you, why are there flowers and green trees in South Africa? Look at more sites which are in the opposite hemisphere from yours as well as sites in your same hemisphere, without mentioning the term "hemispheres" just yet. What is the pattern here? Are there specific portions of the world where everyone seems to be having the same seasons we are, while others are experiencing the opposite season? What is the biggest pattern: our top half of the world has one season, but the other half does not. How can that happen?

"Discovery consists of looking at the same thing as everyone else and thinking something different."

— Albert Szent-Gyorgyi

"We have to abandon the idea that schooling is something restricted to youth. How can it be, in a world where half the things a man knows at 20 are no longer true at 40 -- and half the things he knows at 40 hadn't been discovered when he was 20?"

—Arthur C. Clarke

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

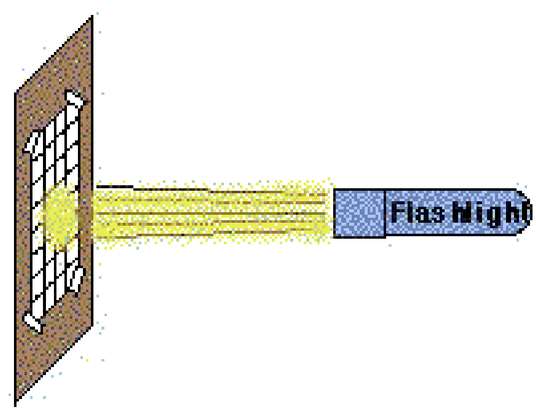
For this age group, the Thread focuses on using some math and building some simpler devices for the classroom. By this age, students are able to count blocks and understand simple concepts about area. So, we'll encourage this. We won't go outside with the clipboard apparatus as we will with the upper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

Additional Resources

The Keys to Inquiry
Telling Time Without a Clock
Word Lore
Related Books For Children
Assessment Ideas

The Keys to Inquiry

An introductory guide to constructivism and inquiry-based learning in the elementary school classroom

By Tina Grotzer, Harvard Project Zero, Harvard Graduate School of Education

"We learn best when we learn from our own experiences."

"Children need to be active learners, seeking answers to questions that they care about."

"Science should be hands-on and minds-on so that children make sense of what they experience."

The goal of the Everyday Classroom Tools Project is to provide opportunities for students to learn that inquiry and their own experiences can help them achieve a deeper understanding of their world. It aims to foster a spirit of inquiry in all students. These goals promise to help students grow into life-long learners who are curious and set out to seek and achieve deep understanding of the world that they live in.

This document has two sections. The first is a series of six brief essays to address the kinds of questions teachers often have about inquiry based learning and learning from one's experience. The intent is to place the central concepts of The Everyday Classroom Tools Project in context--to provide a sense of the variety of ways that the concepts have been thought about as well as how they are interpreted in this project. These essays are written for a teacher audience. The second section is a set of big ideas, questions, and attitudes that are central to the project. This section is written with the expectation that teachers will communicate these messages to their students.

The Keys to Inquiry

Section I: Inquiry-Learning and Learning from One's Own Experience

Inquiry-Learning

"Inquiry learning" and "learning from one's experience" are at the core of the Everyday Classroom Tools Project. What does this mean, in theory and in practice? While these are terms that are used often in the current science literature, its important to unpack what they mean to consider how they are intended in the Everyday Classroom Tools Project and how this relates to the array of meanings people in the field of science education attach to them.

•Before reading on, take a few minutes to ponder the phrase "inquiry learning." What images does it conjure up?

If you envisioned images of children actively posing questions, seeking answers to questions that they care about, demonstrating a strong interest in outcomes, and discussing their theories and ideas with others, you've shared in a glimpse of what makes educators so excited about the possibilities of inquiry-based learning. At its best, inquiry-based learning makes excellent educational sense.

If on the other hand, you envisioned a chaotic classroom where children were doing things, but weren't clear about what they were doing, or what could be understood from it, or what could really be known from what they found out, you've shared a glimpse of what gives some educators pause about taking the plunge into inquiry-based learning. At its worst, inquiry-based learning can result in miseducation. Either vision is possible. So what can you, as teachers, do to enable the first vision?

Throughout these essays, the issues that teachers need to keep in mind to help children learn well through inquiry and to develop deep understanding are presented. The "Points for Practice" are intended to help you create the first vision and avoid the second.

Knowledge as Constructed

Learning from one's experience and through one's questions is based on a philosophy called "constructivism," put forth by Piaget and others. According to constructivism, we don't just *absorb* understanding, instead we *build it*. Learners need opportunities to figure out for themselves how new learning fits with old so that they can attach it to what they already know, making it part of their existing knowledge structures or "assimilating it." When they figure out that new learning doesn't fit with old learning, they need to restructure their current understandings to fit with the new knowledge or to "accommodate it." These processes, assimilating and accommodating, are part of learners' theory building as they make sense of the world.

What does this mean for the classroom? In part, it means that children cannot just sit like sponges and absorb information. They must *do* something with it. They need to be engaged in activities that help them build understanding. Beyond this, it means that often the child is the best judge of what questions he or she needs to explore to make sense of the information before him or her. For instance, if a class is engaged in an activity on weights and measurement and a child is trying to figure out if you could use pebbles as weights to measure with, introducing a particular standard for measuring weight eclipses that child's opportunity to construct an understanding of whether we need standards of measure and what purpose they serve.

Research shows that unless children actively seek connections in their learning, they are not likely to remember what they've supposedly learned. Not only this, they often cannot apply concepts. The learning is inert or has a ritualized nature. It is also unlikely that children will discover areas of misunderstanding if they don't actively grapple with the ideas. Educational Researcher, David Perkins writes about the problems "fragile knowledge." Fragile knowledge hurts learners and does not empower them to understand or deal with their world.

While most teachers find the central concepts of constructivism appealing, the concepts also tend to raise a lot of questions. The translation from theory to practice contains many possible stumbling blocks. The largest stumbling block has to do with helping students to build understandings that will serve them well in today's world. Constructivism and inquiry-based learning can lead to many dead-ends in that children find out what doesn't work instead of what does; or they find out that they asked the wrong question; or that what they did won't help them to answer the question that they want to answer. These *are* valuable understandings. They help students learn a lot about the process of science and what one must think about when trying to answer certain kinds of questions. However, they don't necessarily help children construct present-day understandings of how the world works.

After all, while individual scientists might spend an entire life time developing an understanding of an isolated phenomenon, we have an accumulated wealth of scientific information that no learner could entirely reconstruct in the course of one lifetime. It has been argued that this is children's rightful inheritance.

The "Discovery-Learning" Movement and "Mediated Constructivism"

Such issues are similar to questions raised in response to the Discovery-Learning movement of the 1960's. Students were encouraged to engage in hands-on tasks to discover science principles. Too often, students didn't have a clue as to what they were doing and why. Activities were hands-on but they weren't necessarily minds-on. Too often, the questions weren't posed by students and they may not have understood why the questions being asked were relevant. Students were learning important messages about discovery and the process of science, but without adequate scaffolding of student understandings, it was difficult to know exactly what science principles students were discovering.

How to strike a balance between children's constructing of understanding and their "rightful inheritance" to an accumulated wealth of scientific understanding presents a puzzle that can be addressed through the work of Russian philosopher and psychologist, Lev Vygotsky. According to Vygotsky, children learn within a "zone of proximal development" which is defined by the difference between the level of understanding that children can achieve on their own and that which they can achieve with adult guidance. The role of the adult is to scaffold children's building of understanding by asking guiding questions and providing opportunities for certain experiences.

From the joint work of Vygotsky and Piaget, arises a concept that can be called *mediated constructivism*. Children construct understanding by learning through their experiences and their own questions but the process is mediated by adults who hold scientific understandings of how the world works. It allows for building understanding as part of a society or community of learners. Children engage in Socratic discussion of ideas, guided by the teacher, to help them build new understandings.

Mediated constructivism involves a thoughtful choreography between student and teacher. The teacher must constantly study the student's evolving understanding, assess what path it is on, and help the child to have and to take advantage of opportunities that enable the child to construct new and more sophisticated understandings. The teacher must guide while taking care not to be directive such that it undermines the child's incentive to explore the question. It doesn't mean that teacher can't arrange certain experiences for children. It does mean that the teacher needs to pay attention to how students are making sense of the experiences and whether the experience helps them to answer a question that they care about.

Pictures of Practice

What might mediated constructivism look like in practice? Here are some snippets from a second grade classroom discussion around a question that arose about where the stars go during the day.

- Teacher: So, let's think about Michael's question, "Where do the stars go during the day?" Michael, what made you think to ask that?
- Michael: Well, you can't see any stars during the day time but then at night lots of them come out.
- Teacher: Okay, so when you look at the sky during the day, you can't see any stars but then you do see them at night. Why might that be so?
- Michael: They go away when the sun comes out and come back at night.
- Teacher: What do some of the rest of you think happens? Let's collect all of our different ideas about what happens.
- Emma: Maybe they're on the "night side" of the sky, so when we spin around we don't see them anymore.

- Teacher: Okay, what do others think?
- Dion: Maybe, they turn off during the day but they're still there.
- Ashley: I think that the clouds and sun and stuff cover them up.
- Teacher: Can you say more about what you mean by "cover them up" Ashley?
- Ashley: ...just make it so you can't see 'em, I don't know.
- Teacher: Perhaps you can think about what makes it so you can't see them.
- Jared: I think that it's not really covering them up but you can't see em because the background isn't dark enough, like when we caught the snowflakes, you wouldn't see it on white paper so we looked at them on black paper.
- Teacher: Okay. ...Seth?
- Seth: I agree with Jared.
- Teacher: What makes you agree with him?
- Seth: Well, it's like camouflage because there's no black to see the stars, they blend in.
- Teacher: Does anyone else agree? And if so, why?
- Donna: It's like you just can't see them. Maybe you need sunglasses. (laughter)
- Annie: But I saw the moon once in the day time and how come it didn't getcamouflaged?
- Teacher: hmm... now that's a puzzle. These are interesting ideas. What could we do to try to figure out which ones help us answer Michael's question?
- Annie: We could look for stars in the day time.
- Jared: We could look at a map of the stars to see if they're only on the night side like Emma said.
- Seth: We could shine a bright light at night to see if it makes the stars go away.

(Laughter follows)

- Tommy: We can't make the stars go away!
- Teacher: Ah, maybe not, but let's talk about Seth's idea. Seth is thinking about possible ways of finding out. He is doing what good scientists do. Is there a way that we could use a bright light to see how it affects our ability to see the stars?

(There is no response and some students shrug their shoulders.)

- Teacher: Okay, well, we'll come back to that question. In the meanwhile, perhaps we could collect some other information. Over the week end, look to see if you can see any stars or the moon in the day time.

The teacher sends home a memo to parents suggesting that next time they with their children near a big city at night or in a football stadium with lights on, or simply in their backyard with a spotbeam on, they see how many stars are visible and then do it again when they are away from bright lights. She also brings in a string of Christmas lights along with a spot light and some black paper so that the class can contrast the visibility of the Christmas lights against the two backgrounds.

Upon Reflection...

Okay, let's revisit pieces of the conversation to look closely at how the teacher is mediating the children's construction of understanding :

- Teacher: So, let's think about Michael's question, "Where do the stars go during the day?" Michael, what made you think to ask that?

[*Here the teacher starts with a child's question. She may have chosen this question to focus on because she saw it as having the potential to help them understand more about what they experience in terms of day and night. It is always difficult to choose which questions to spend limited classroom time on. This question may have been one that a number of children raised or expressed an interest in.*]

- Michael: Well, you can't see any stars during the day time but then at night lots of them come out.
- Teacher: Okay, so when you look at the sky during the day, you can't see any stars but then you do see them at night. Why might that be so?

[*Notice that the teacher asked the child to connect the question back to his experience, to what it was that he observed that made him ask the question in the first place. She then asked him to tell about his own theory of what is happening. Children's implicit theories impact how they construct new theories. She knows that there will need to be new and convincing evidence to help Michael adopt a new stance.*]

- Michael: They go away when the sun comes out and come back at night.
- Teacher: What do some of the rest of you think happens? Let's collect all of our different ideas about what happens.
- Emma: Maybe they're on the "night side" of the sky, so when we spin around we don't see them anymore.
- Teacher: Okay, what do others think?
- Dion: Maybe, they turn off during the day but they're still there.

[*Here the teacher asks for lots of different ideas about what might be happening to open up a realm of possible explanations. She doesn't stop with just a few ideas but continues to encourage children to consider what alternative explanations could be. If a child offered an idea that seemed unlikely or others thought was in some way "silly," she would have reminded them that scientists need to think openly about what they experience.*]

- Ashley: I think that the clouds and sun and stuff cover them up.
- Teacher: Can you say more about what you mean by "cover them up" Ashley?
- Ashley: ...just make it so you can't see 'em, I don't know.
- Teacher: Perhaps you can think about what makes it so you can't see them.

[*Here the teacher asks Ashley to tell more about her idea. Often the children are just figuring out what they think and may not have clear access to their thoughts. The teacher provides an opportunity for this, but doesn't push Ashley for an answer at this point. The teacher leaves Ashley with a follow-up, guiding question to help her in thinking about it further.*]

- Jared: I think that it's not really covering them up but you can't see em because the background isn't dark enough, like when we caught the snowflakes, you wouldn't see it on white paper so we looked at them on black paper.
- Teacher: Okay. ...Seth?
- Seth: I agree with Jared.
- Teacher: What makes you agree with him?
- Seth: Well, it's like camouflage because there's no black to see the stars, they blend in.
- Teacher: Does anyone else agree? And if so, why?
- Donna: It's like you just can't see them. Maybe we need sunglasses.

(laughter)

[*Some of the students are starting to support one idea that they think has potential. The teacher invites discussion of that idea*]

- Annie: But I saw the moon once in the day time and how come it didn't get camouflaged?
- Teacher: hmm... now that's a puzzle. These are interesting ideas. What could we do to try to figure out which ones help us answer Michael's question?

[*Here the teacher direct students to a puzzle that Annie found. She also asks them to think about what experiences or evidence could help them answer the big question. This directs students back to experience, collecting data, and looking for patterns in the real world that address their questions.*]

- Annie: We could look for stars in the day time.
- Jared: We could look at a map of the stars to see if they're only on the night side like Emma said.
- Seth: We could shine a bright light at night to see if it makes the stars go away.

(Laughter follows)

- Tommy: We can't make the stars go away!
- Teacher: Ah, maybe not, but let's talk about Seth's idea. Seth is thinking about possible ways of finding out. He is doing what good scientists do. Is there a way that we could use a bright light to see how it affects our ability to see the stars?

[There is no response and some students shrug their shoulders.]

- Teacher: Okay, well, we'll come back to that question. In the meanwhile, perhaps we could collect some other information. Over the week end, look to see if you can see any stars or the moon in the day time.

[*The teacher encourages the students to look at what they can see, at what their own experience tells them. This validates the importance of their own observations and experiences in finding out the answers to scientific questions.*]

The teacher sends home a memo to parents suggesting that next time they with their children near a big city at night or in a football stadium with lights on, or simply in their backyard with a spotbeam on, they see how many stars are visible and then do it again when they are away from bright lights. She also brings in a string of Christmas lights along with a spot light and some black paper so that the class can contrast the visibility of the Christmas lights against the two backgrounds.

[*The teacher also recognizes that certain kinds of experiments may be beyond the children's ability to generate given their own limited science knowledge and understandings of scientific process. So she creates opportunities for them to gain new experiences relevant to the big question that they are grappling with.*]

Teacher Response

Here are some of the kinds of questions that teachers tend to ask about mediated constructivism.

- **My students are young and have so little experience. How do I help them build understandings when there is so little to help them build it from?**

  While even young children do know quite a lot about the world around them, this is a real challenge and one that teachers of the youngest children face most. In part it means thinking carefully about the kinds of experiences that you in partnership with parents can provide to help children gain and think about particular questions that children are grappling with. In choosing from children's questions to decide which ones to pursue as a class, teachers need to think about the kinds of experiences those questions assume knowledge of, start where the children are, and provide experiences to get them to where they need to be. At different ages, there are questions that teachers will decide not to pursue because it isn't possible to offer the kinds of experiences that will help the students to build a satisfactory understanding

- **How do I keep students on track when they are constructing understandings? They come up with some pretty unorthodox explanations for why things are the way they are.**

  It certainly is true that the path to constructing scientific understandings is a rocky one. As discussed further in later essays, children have certain tendencies that influence the kinds of understandings that they create. For instance, they don't necessarily worry about constructing coherent and consistent explanations for the different instances of the same phenomenon. Through guiding questions and introducing areas of discrepancy, teachers can keep student understandings along a path towards greater explanatory power. Teachers should view their role of helping children evolve better understandings more than one of immediately helping children adopt the scientifically accepted understanding.

Points for Practice

•Try to connect children's questions to what they experienced that made them ask the question.

•Help children to discover what they already know and believe as a starting place to work from in constructing new understanding.

•Help children to see how they can collect evidence from their own experience that helps to inform their questions.

•Use guiding questions to help children develop more sophisticated understandings.

•Use sharing and discussion to help children consider their individual ideas in relation to the ideas of others.

•Create opportunities for children to gain experiences that will help them think more deeply about their ideas.

•Help children identify puzzles that will enable them to push beyond ideas that aren't workable.

The Epistemology of Science

Inquiry-based learning aims to teach much more that science content or science process as we typically think of them. It provides the opportunity for learners to learn how knowledge is created in science, what scientists do to find out and what it means "to know" something in science. This is often referred to as the epistemology of science.

What does it mean to learn the epistemology of science? Instead of learning "facts," students are learning such things as how information is generated, what tools and techniques scientists have at their disposal to help them generate information, what beliefs scientists share about what constitutes knowledge, and what attitudes and habits of mind scientists bring to their work. This is a much more expansive view of what is involved in science learning. The Everyday Classroom Tools Project is about helping children learn how scientists think about and frame investigations by helping the children to rediscover their own curiosity and to cultivate the budding scientists within each of them.

Why is it so important to help children learn the epistemology of science? Research shows that students are sometimes baffled by what they perceive as the "games of science." Scientists engage in certain ways of thinking and generating knowledge, for instance, isolating and controlling variables. These can be puzzling to students who have not had the opportunity to learn how these "games" work and how they are important in the larger context of knowledge generation. Not understanding these "games" often divides those who feel comfortable pursuing math and science and those who don't. Often those who don't feel comfortable with the games are women and minorities. This may contribute to lesser numbers of women and minorities in math and science.

Beyond this, most students carry around certain misconceptions about the nature of disciplinary knowledge. For instance, they often view science as a collection of dusty, old facts--rather than a dynamic, evolving state of how we best understand the world. School practices that don't provide opportunities to learn how scientists come to know and find out can contribute to these misconceptions.

In talking with children about epistemologies, it is often helpful to talk about it in three different ways: as roles; as tools and techniques; and as ways of knowing. The emphasis that the teacher places on each of these depends in part upon how young the learners are and how much "science talk" they have been engaged in. In the early elementary years, one might talk primarily about *roles*, what is it that scientists do and why do they do it? One can also introduce talk about the tools of the discipline. What kinds of *tools and techniques* do scientists use to help them find out? For instance, scientists try to create "fair tests" by attempting to control for extraneous variables. Eventually, teachers with older students should talk with students about the "rules" (and the rationale for them) that scientists employ for knowing and finding out. For instance, science involves the purposeful discarding of theory as discrepant evidence arises and theories with greater explanatory value evolve.

Pictures of Practice

What might such a discussion look like in the classroom? How might teachers of different age groups talk differently about epistemology or processes for finding out and knowing in science? Here are some snippets from classroom discussion at different grade levels:

Kindergarten:

- Jared: My car is the faster one.
- Josh: Can't beat mine!
- Teacher: How can we find out which one is fastest? What would be a fair test?
- Jared: We could have a race.
- Teacher: Should we have both cars start at the same time?
- Josh: yeah, cause otherwise it's not fair.
- Teacher: What about at the same place? What if we started Josh's car up here and Jared's back there?
- Josh: My car would win!
- Jared: But it wouldn't be fair!!
- Teacher: That's right, it would make Jared's look like it took longer to get to the finish cause it has further to go. When a scientist wants to com pare something, like your two cars, he or she tries to make every thing else the same so that the only difference is how fast the cars go.

Second Grade:

- Teacher: Travis wondered if our bean plants really need to have sun to grow cause he found some plants growing under leaves. So let's think about it together. Can you tell about the plants you found, Travis?
- Travis: They were under a pile of old leaves where the sun couldn't get to and when we moved the leaves we found them.
- Teacher: Can you describe them?
- Travis: They were sort of yellow colored and skinny, I think that they were some flowers my mom planted.
- Teacher: What do the rest of you think? Do our bean plants need sun to grow?
- Kate: Everything needs sun or it would be really cold and dark and nothing could grow.
- Timmy: Well, I saw a plant, an Indian Pipe, in the woods once that my dad said didn't need sunlight.
- Teacher: How would a scientist test out whether or not bean plants need light? What would he or she do?
- Chloe: Maybe put one in the dark and see if it grows...
- Teacher: That's a good idea, Chloe. A scientist might try it to test the idea. Let me ask you some questions about that. If we put a seed in the dark and it did grow, what would that tell us?
- Travis: That plants can grow in the dark.
- Scott: Nooo...That doesn't mean that all plants can!
- Travis: Well at least the bean plant could.
- Teacher: What if we put it in the dark and didn't grow? What would that tell us?
- Ariana: ...that it can't grow in the dark?
- Tara: It could have just been a bad seed or maybe we forgot to water it enough.
- Teacher: Okay, how can we solve the problem of maybe getting a bad seed?
- Scott: You could plant a bunch of seeds.
- Teacher: Okay, a scientist would probably test lots of seeds. What about the watering problem?
- Chloe: We should see how much water bean plants need and give them the right ‘amount.
- Teacher: Okay, let me ask another question. Suppose the plant in the dark grew some. Would you know if being in the dark made a difference in how it grew?
- Emma: Not unless you check beans that aren't in the dark.
- Teacher: Okay, so a scientist might compare beans that grew in the dark to beans that grew in the light. The scientist would try to keep everything else the same except the amount of light it had so that he or she would know that the light made a difference. What are some of the kinds of things the scientist would try to keep the same to make it a fair comparison?
- Ariana: how much dirt
- Scott: the kind of dirt, too, I have two, the size of the pot, too.
- Chloe: how much water
- Teacher: Shall we try our experiment?

Fifth Grade:

- Teacher: Okay, so what patterns do we notice in our shadow stick data?
- Eddie: The shadows are getting longer each day.
- Teacher: Ah... Can we make any predictions about what our future data will look like based on the patterns that we see.
- Gina: It will probably just keep getting longer and longer until... I'm not sure what.
- Steven: Well, till the length of the sunlight changes.
- Teacher: Okay, so you're thinking that the length of the shadows has to do with how long the sun is out?Okay so we have a theory about length of time the sun is out making a difference. What kind of evidence would support your theory?
- Steven: If the shadows stopped getting longer when the length of sunlight is lessening.
- Teacher: What kind of evidence would contradict your theory?
- Steven: I guess if the shadows did keep getting longer when the sunlight time was lessening.

A few days later....

- Steven: It's not just the length of time, it's the position of the sun seems to make the shadows longer and shorter at certain times of the day.
- Teacher: What made you want to revise your idea?
- Steven: cause I thought about it and thought well, if the sun was out a really long time, but stayed in one place, like right overhead, it wouldn't make our shadow change size. Then when I looked at where the sun was when we went outside, I saw that the position was different and it reminded me to include position in the theory.
- Teacher: Okay, so we'd like to revise our theory to include information about the position of the sun affecting the length of the shadow. Scientists often make informed guesses based on the patterns that they see but then they make sure to keep their minds open to new information and evidence that might invalidate a theory or make them want to modify it in certain ways.

Each discipline can be viewed as a lens on the world. Certain kinds of questions, tools, and ways of thinking about knowledge are common to each lens.

What are some of the kinds of questions that scientists might explore?

How can I find out about what I can't see, what happened before, what could happen?
How can I find out how it works?
How can I find out what causes what?
How can I prove it?
What evidence can I find for what I think is so?
What patterns can I find? How can I show the patterns I found to others?
How can the tools of math help me to find out?
How can I measure it?
How can I use data to prove it?

What are some of the tools and techniques that scientists use to find out?

experimental method
controlling and isolating variables
observation
collecting data or information
measurement
graphing
mathematical relationships such as means, modes, ranges, etc.

What are some assumptions that scientists make about what knowing looks like?

An objective, "knowable" reality is assumed.
There are regular, orderly phenomenon in our world.
To some extent, we can control situations to know what causes what.
Patterns in the world can be understood and manipulated by quantifying them.
Past information or what happened before can help us predict what will happen next time.
Certain rules enable us to carry out tests that approach objectivity. There is a purposeful attempt to minimize subjectivity.
Abstractions can help us explore the concrete world.
Concrete examples and models can help us understand abstractions better.

Points for Practice

•Talk with children about ways of finding out answers to the questions that they are interested in.

•Help children to see that knowledge changes. As we learn more, we change our ideas about how the world works. Try to share examples of "we used to believe..., but then we learned..., so now we think...."

•Talk explicitly with children about the process of science, about the assumptions that are made and why they are important.

•Many teaching materials implicitly include process experiences and information but never outwardly discuss the processes and the reasons for them with children. Modify existing materials so that there is explicit reflection on the processes for knowing and finding out.

•Seek out materials that help children think about the "whys" behind scientific epistemology, such as books like, How to Think Like a Scientist: Answering Questions by the Scientific Method, by Stephen Kramer.

•Help children realize that science is a way of knowing and understanding the world that is learnable. They can all learn to think like scientists. Some of the tools and techniques they'll be able to understand now, others will make greater sense to them as they continue to study and explore science.

The New Frameworks and Content Standards

Increasingly, the new standards and frameworks set forth by educators, scientists, and policy-makers reflect the need for a greater constructivist approach to teaching science. They recognize the need to emphasize process, and to understand the nature of scientific inquiry.

The new standards call for deep understanding of the ways of scientists--how they come to know and find out, how they think about problems, what they consider to be valid information, and so on. These are the kinds of skills that the Everyday Classroom Tools Project aims to cultivate. The standards also call for helping students learn the habits of mind, the attitudes and dispositions of scientists. By working with scientists in the Everyday Classroom Tools Project, students have an opportunity to come to understand the kinds of attitudes and habits of mind that characterize their work.

What is known about teaching such habits of mind? Researchers David Perkins, Shari Tishman and colleagues stress that helping students develop effective habits of mind entails helping them develop: 1) sensitivity to occasions for certain types of thinking; 2) skills that will enable them to think well; 3) and the inclination to sense opportunities and apply those skills.

How does all this translate into what students need in the science classroom? It suggests that:

1. Students need opportunities to engage in scientific thinking.

A wealth of opportunities creates a rich context for learning. These opportunities should not be "handed" to kids. Rather, students should be encouraged to be sensitive to opportunities for good scientific thinking. They should look for "thinkpoints" or places in the curriculum and in the course of their lives where thinking like a scientist can help them live better, more interesting, more informed, and more thoughtful lives.

2. Students need models of what good scientific thinking looks like and a vocabulary to talk about it.

Good thinking can be harder to learn than other things, because so much of it goes on in people's heads and isn't easily available for examination. Students are helped by teachers who talk their thinking and the rationale for it out loud. "For instance, now I'm going to consider the evidence for this claim. I am going to think about the source of the evidence and whether or not the source is a reliable one. Here are the criteria that I am going to use...."

3. In addition to models of good scientific thinking, students benefit from explicit reflection upon, and self-assessment of, scientific thinking.

A language to talk about scientific thinking and reasoning enables us to unpack what is going on in our minds and share it with others. For instance, a teacher might say, "I'm comparing the two theories in my head to see which better explains what happened but I'm finding it hard to hold all the ideas in my head at once. I think I will download the ideas onto paper so I can think about them without having to remember them all at once." This gives the students a glimpse into what her thinking is like and what she can do to support it.

It is important to be explicit about why certain types of thinking are better than others. Too often, we assume that students notice and understand the rationale for our choices when indeed they may not. If students are to learn good patterns of thinking, we need to help them see what they are, why they work, and instances in which they apply.

4. Students need to be alerted to pitfalls of good thinking and what to do about them.

People often fall into certain pitfalls in reasoning and thinking. Without focused instruction to learn new ways of reasoning, people persist in these patterns. For instance, in science, it is common to confuse correlation and causality. Students will persist in these tendencies unless they have models to help them think about causality and correlation differently.

5. Students need to see the value of the forms of thinking in science to be inclined to use them.

It isn't enough to notice opportunities for good thinking or even to know how to do it. Students also need to see a value in good thinking such that they are inclined to make the extra effort to do it. Therefore, teachers need to make certain that children see the pay-offs of their thinking: increased understanding; solving a puzzle; answering a question, feeling in control of the learning process, and so on.

Some Habits of Mind Called for by the American Association for the Advancement of Science

Integrity	Skepticism
Openness to New Ideas	Fairness
Diligence	Imagination
Curiosity	

(Rutherford, F. J. & Ahlgren, A. (1990). *Science for All Americans.* New York: Oxford University Press.)

Pictures of Practice

What does it look like to teach the skills, attitudes, and inclinations from the standards in the classroom? It is similar to how a teacher talks about epistemology--the way a scientist thinks and finds out. Here are some snippets of conversations you might hear:

- Teacher: If a scientist wanted to answer that question, what might she do?
- Michael: She would test it to get some information.
- Teacher: What kind of information would be good evidence in this case?
- Cindy: Wow, I noticed that this leaf has really different patterns of color than this one even though they come from the same tree.
- Teacher: That is very careful looking, Cindy. What does that make you wonder about?
- Timmy: His shadow seems taller than mine, but we're exactly the same height!
- Teacher: What are some ways that we could find out if his shadow is taller or not? Do we have any tools to help us?
- Sara: I'm not really sure if this experiment answers our question. We're not sure if we measured the shadows right and that could mess up our results.
- Teacher: It is important to think about the quality of the information and to consider whether it tells you what you think it does. Let's think together about what problems if any, your data set might have.
- Chloe: Hey, doesn't it change the temperature of the solution when we put such a big thermometer in it? The thermometer has been

sitting on the cold table, it must be colder than the solution.

- Teacher: Ahh, there's some very careful thinking. What do others think about Chloe's critique of the procedure? Does it impact what we are trying to find out and if so, how?
- Steve: I think it could affect the temperature of the solution. But I don't see how you could ever take anything's temperature without doing that.
- Teacher: It sounds like you're identifying an important puzzle or problem in science. Let's take some time out to think about the nature of the problem in detail and to think broadly about potential solutions.
- Devon: On the way to school, I noticed that there was a lot of muddy water in the river near the new construction site. I never realized how much we needed the concrete walls they're building next to the new mall to keep the river from looking so dirty. It's good that they're making the mall and those big walls.
- Teacher: Let's think together about how the muddy water, construction, and walls are related. In order to figure out what is causing what, we'll need to ask ourselves some questions. For instance, what are some things that contribute to the river getting dirty? Was the river looking dirty before the construction? What are some other questions we might ask?

Points for Practice

•Build upon opportunities that students notice for using scientific thinking. Use these as opportunities to teach the skills of good scientific thinking while teaching content. For instance, when students notice that where they place the seesaw along the supporting beam (fulcrum) matters, use it as an opportunity to get them to make predictions, consider what good evidence for their predictions would look like, design a test of their predictions and so forth, while they are learning about levers.

•Introduce language to talk about scientific thinking. If a good word to explain what you are trying to explain doesn't exist, make one up with your students.

•Explain to students why you reason about certain problems in certain ways. Share contrasting examples to demonstrate what less careful thinking in the particular situation looks like. Be explicit with kids about why certain types of reasoning are better than others.

•Talk your thinking out loud to help students "see" it.

•Be alert to instances of poor thinking or misconceptions about thinking and help students learn how to avoid them.

•Create opportunities for students to work with scientists so that they can learn firsthand how scientists think about particular problems.

Development Interacts with Children's Sense-Making

One of the challenges to inquiry-based learning is knowing how to handle issues of development. Teachers are faced with a number of them. For instance, "We started off on a question that the students were interested in. It sounded simple enough and then all of a sudden, we were into territory that was way over their heads..." Or "The children start coming up with ideas that seem to make a lot of sense, I'm just not sure how to get them to see that scientists think about these things differently." And "I could use a model and a formula to help show the idea, but they don't yet understand the relationship of the model or formula to the real phenomenon or of the formula to the model." These certainly are important concerns and signal areas that need special thought and attention. Let's consider each area in turn.

1. Children's questions sometimes lead to complexity that they're not yet equipped to handle.

"We started off on a question that the students were interested in. It sounded simple enough and then all of a sudden, we were into territory that was way over their heads..."

This is a common concern of teachers who use inquiry-based learning in their classrooms. The students' curiosity about a question leads to complexity that the teacher doesn't quite know how to communicate to young children. Questions that are bound to interest young children, such as "What makes the colors?" "Why do sounds seem louder at night?" "What does it mean to reflect?" can quickly lead to physics concepts that are over their heads. The problem isn't about getting students to understand *some* things about the phenomenon that they are studying--it's about getting them to understand it deeply enough such that they can explain it and can understand the "whys" behind it.

What kinds of solutions have teachers come up with? Here's how some teachers handle the issue:

- "I communicate to kids that there are lots of connections in the world and whenever we study a topic, sooner or later we'll come to a connection that we may not be able to understand yet, but that's okay, we know more than we did before"

- “There are different levels of understanding. Some topics can't be understood at the deepest levels at certain ages. I try to let my students know that they need to come back to topics, you don't just learn them once. You can always come back and explore the topic deeper."

- "I try to scope out the questions that we are going to spend a lot of time with in advance. I look for concepts that will serve as obstacles to understanding at this age. If there are a lot of them, it's not a question that we spend a lot of time on."

2. Children have great ideas, but they're not always very scientific.

"The children start coming up with ideas that seem to make a lot of sense, I'm just not sure how to get them to see that scientists think about these things differently."

Research shows that at a very young age, children theorize about their world and why it is the way it is. They come up with intuitive theories to explain many things. These theories tend to be fairly resistant to change because they make sense to the child, they represent the understandings that children have figured out. Researchers have identified a number of characteristics of these theories. 1) Because they represent the individual child's experience, they can be personal and idiosyncratic. 2) Children don't necessarily hold coherence as a criterion for their theories so the theories may be customized for each event explained. 3) The theories tend to be stable and resistant to change. Children are often quite comfortable with the sense that they have made and have no reason to change a serviceable theory.

This has both a positive and a negative side for inquiry-based learning. It says that children actively seek to make sense of their worlds and that their curiosities help to motivate learning. It also suggests that they have many "figuring out" tools to help them learn. On the other hand, understandings that children evolve do not always represent current day scientific understandings. This presents a challenge for teachers.

Research shows that kids bring a "sense-making mission" to their worlds and that they have many "figuring out" kinds of tools to help them build their theories. Infants as young as six weeks of age demonstrate some understanding of causal contingencies and in the first six months babies show surprise at events in which their causal expectations are violated. Children seek out patterns in the world and attempt to explain those patterns. Children also hold certain perceptual tendencies. These are largely helpful, thought they can support or limit understanding depending upon how they are applied and the phenomenon in question.

Children's Science Learning

1. From an early age, children develop ideas related to how the world works and what different science words mean.
2. These ideas are usually strongly held.
3. These ideas may be significantly different from how scientists view the world.
4. These ideas are sensible and coherent from a child's point of view.
5. Traditional teaching often does little to influence or change these ideas.

Table reprinted with permission from Math/Science Matters:
Resource Booklets on Research in Math and Science Learning

At least three broad perceptual tendencies have been discussed in the science learning literature. 1) Children's thinking tends to be based upon what they can observe. They learn most readily from what they can gather through their senses. In many instances, this is a useful tendency. In cases where appearance and reality diverge, it can trip them up. 2) Children consider absolute properties or qualities before those that involve interactions. This often leads straightforwardly to accurate conclusions. However, it can also lead to misunderstandings of complexity. 3) Children tend assume a linear, unidirectional relationship between events and effects that they observe. Again, this often leads to straightforward, accurate answers but in some instances it leads to a misunderstanding of extended and complex effects.

How Can Children Be Taught Scientific Views of the World?

1. Lessons need to start with the ideas that children hold. The current understandings must be revealed.
2. These ideas need to be explored as possible solutions.
3. Children need to be confronted with ideas that are discrepant with their ideas. It is important to provide evidence that is contrary to their expectations on something that they care about.
4. Children need opportunities to compare the differences between the ideas.
5. Children need opportunities to connect the new idea broadly to the world. Otherwisethey may see it as an isolated case.

Table reprinted with permission from Math/Science Matters:
Resource Booklets on Research in Math and Science Learning

We need to help students see when their intuitive theories do not account for scientific phenomenon. They need to see when outcomes are *discrepant* with what their theories would predict. This creates dissonance which invites them to evolve new and more scientifically-accepted theories. They need opportunities to *compare* the differences between the ideas--to see how one has greater explanatory value than the other. Finally, children need to seek connections to *help* them find broad applications for the new theory so they don't view it as an isolated case.

What methods can teachers use to encourage students to reveal and revise current understandings in an inquiry-based approach?

•Interviewing to see how students construe word meanings.
•Interviewing using questions of interpretation that reveal hidden misconceptions and limits of understanding.
•Developing activities that start with a deep question--one that is revealing of current conceptions (Sometimes it is the same activity as the one that creates a discrepancy between an expected outcome and an actual outcome.)
•Asking the question another way.

•Recording kids' talk around a science problem or everyday event.
•Offering students' everyday instances./Asking them what would happen.
•Giving "homework" with everyday instances and see what they reveal to parents and others.

3. The means to an understanding represents developmental hurdles.

"I could use a model and a formula to help show the idea, but they don't yet understand the relationship of the model or formula to the real phenomenon or of the formula to the model."

Sometimes it's not the understanding itself that poses the first developmental challenge. There are some instances where the tools that teachers would use to help students achieve understanding contain developmental hurdles that make them more or less useful at particular ages.

Children's understanding of models represents one such challenge. Around three years of age, children begin to show early understandings that a model is a representation of something else. For instance, research by Judy DeLoache shows that they could use a model room to guide their actions in finding the location of an object in a real room. These early understandings suggest promise that fairly young children can understand some things about models, yet understanding a model as a representation requires an extra leap in that the model is a thing unto itself. Even if the child perceives it as similar to the original room, the child must also reflect upon and realize that it is being used as a representation of the room. According to researcher Usha Goswami, understandings such as this are a form of analogical reasoning in that children need to recognize the relational similarity and reflect upon the similarity in structure. Using a model to show something about a scientific phenomenon involves 1) understanding the model to be a representational object, not the object itself; 2) understanding the process as it applies to the model; 3) considering how relationship between the model and the process is analogous to the phenomenon in question; 4) holding both in one's head at once; 5) mapping the analogous relationships to enable understanding of the phenomenon in question. That's a lot to think about!

Research shows that into middle school and high school, students still tend to view models as physical copies of reality rather than conceptual representations. Students benefit from scaffolding to help them understand models as metaphors, and to map the deep structure of the models, and not to get caught up in superficial features of the model.

Despite the developmental challenges of helping students grasp and use models well, research shows that conceptual models are very important to helping students develop math and science concepts. This is in particular contrast to the focus in many schools on teaching students quantitative explanations or formal laws for understanding science phenomenon.

It is important for teachers to seek a balance between determining that a certain avenue to understanding is over children's heads with offering them early experiences that will lead to developing an understanding of the concept. Teachers can bolster early understandings by coming at them in a number of different ways so that the children are not dependent upon models as a sole means towards understanding. There are numerous activities teachers can introduce which will engage their students and also uncover hidden misconceptions.

Pictures of Practice

Rethinking Why We Wear Coats: How Insulation Works
A Third Grade Science Lesson

The following picture of practice describes a lesson in which students are exploring the purpose of insulation and concepts of heat and temperature. It deals with a common misconception that young students tend to hold that their coats are a source of heat energy.

- Teacher: Today, we're going to work on a special question that has do with coats and how they work. I'm going to ask the question in just a moment, but first I'm going to ask that you don't shout your ideas out loud. That's because I want everybody here to think about their own answer and to get a chance to test it out. We're gonna spend two science periods on this so there'll be lots of time to talk about it later.

  Here's the question: If you wanted an ice cube to last for a long time in our classroom, would you make a thick or a thin coat for it? Just think about it, don't say any ideas out loud. We're each going to design a coat for an ice cube. You can make it thick or thin, and everyone is going to have a coat for their ice cube. First, we'll draw a diagram of what we think the coat should look like, what we need, and why we think it will work. Then we'll make the coats. And in our next class, we'll test them out. Are there questions?
- Dillon: Can we work together?
- Teacher: In this case, I want everyone to think about what their own ideas are, so onceyou have your idea on the paper, if someone else's is similar to yours, you can make the ice cube coat together.
- Stefan: Is it really like a little coat with buttons?
- Teacher: No, it's more like a package. (She shows some examples, a plastic container with styrofoam, a balloon, a plastic envelope)
- Crystal: Can we use whatever we want to make it?
- Teacher: Well, I have lots of different materials here, plastic, balloons, styro foam, etc. But what do you think, should we use any kind of material?
- Crystal: Well, we shouldn't use stuff that's way too big or too hard to get.
- Hanna: If we all use different stuff, how will we know if it was the stuff or how thick the coat was that made it melt faster?

(A discussion ensues about how to make a good comparison. Two volunteers offer to make two coats that are exactly the same except one is thick and the other is thin. The students decide that this will help with a good comparison and that the rest of them can make what they want.)

The students set off to design their coats. Some of them decide that a thick coat will "warm up the ice cube and make it melt faster." Others decide that a thin coat will result in the ice cube melting faster because it is a warm day in June and there will be less around the ice cube.

(At the end of the session, the students come back together to discuss what will happen in the next class. How will they do the test? What will make it fair? It is decided that everyone's ice cube should have the same amount of water and be the same shape.)

In the next session, the class discusses their ideas. Each student shows their container and explains why it will work. There are clear differences of opinion. The teacher stresses that no matter what happens with the ice cube, everyone is helping the class to gather important information they are thinking like scientists.

- Sara: I made mine thick because it is hot in the room and I wanted to keep the warm air away from my ice cube.
- Dillon: Well, I think a thick one will make it melt really fast because it will make it hot.
- Teacher: It's great to see you all thinking carefully about your ideas and reasoning them out. All of us are thinking like scientists and the many different ideas in the class room will help us to learn a lot about how coats work.

The teacher gives everyone their ice cube as quickly as possible, removing it from the cooler with tongs and putting it directly into the children's containers. She explains how she carefully measured the water in each cube. In addition, to putting cubes into the two containers that are identical except for thickness, she puts one cube out on a plate without a coat. Some kids think it is the "luckiest" ice cube and will last the longest, others feel "sorry" for it! The class discusses why it is important to check their ice cubes only at certain intervals, realizing that it would throw off their results to check it every few minutes. While waiting, they brainstorm as many different things that they can think of that would be considered coats.

- Susan: a coat of paint
- Teacher: Ah, how is it like a coat?
- Susan: It covers the wall and keeps it from getting dirty.
- Dillon: A jacket
- Teacher: Okay, tell about a jacket.
- Dillon: It keeps the cold away.

[Notice that the teacher does not correct their use of the terms "cold" and "hot" as entities yet. In some instances, the teacher even uses the exact same words back when quoting a child (i.e. Can you tell me how "it keeps the cold away"?) Their language reflects their mental models and ultimately when they shift to a thermal equilibrium model, she assumes that their language will shift as well or that the shift can be facilitated at that time.]

- Sara: a roof is like a coat
- Teacher: Tell how.
- Sara: It keeps the snow and rain out.
- Stefan: Your skin is a coat.
- Teacher: Ah, what are some things that your skin does?
- Stefan: Well, it keeps germs out of your body for one thing.
- Travis: It also holds your insides in!

Eventually, the whole board is filled with things that are coat-like. The children begin to see that these things keep what's out, out and what's in, in leading to new ideas about what constitutes a coat.

They stop to check their ice cubes. Low and behold, those in thin coats are melting faster! Some of the students are very surprised. And that poor ice cube without a coat, it's melting very fast. The class closes up the coats with the ice cubes inside and continues their discussion.

- Teacher: (She draws a diagram of an ice cube on a plate, an ice cube in a thin coat and an ice cube in a thick coat) What is the air temperature in our room?

After checking:

- Travis: 90 degrees
- Teacher: At least what temperature is your ice cube?
- Class: 32 degrees
- Teacher: Can anyone explain how the things we figured out about other kinds of coats might affect the ice cubes?
- Karem: The thick coat helps to keep the hot out and the cold inside.
- Sara: The ice cube in the thin coat has no protection!

[Notice that the students do not yet have a notion of heat as thermal energy and that they speak of hot and cold as entities. This suggests the importance of helping students see where the concept of a coat as "keeping what's in in and what's out out" breaks down. See more on this below.]

Then they go on to consider other cases. What about the student who put his ice cube in a coat with water around it?

- Anat: The water is warmer than the ice cube so it makes it melt faster.
- Teacher: What happens when you put an ice cube into a warm drink on a summer day?
- Anat: It melts fast!

The discussion continues as they consider the different examples of coats that they have tested. "What about the students who used balloons for coats?" and so on...

Later the class checks their ice cubes again. By now, those wearing thin coats made of balloons are merely balloons filled with water. Those in the thickest coats have barely melted. Many students are still surprised at the differences between the thick and thin coats. Again the teacher stresses how important all of the different information is and that it helps us to find out the way that scientists do. She tells the class that getting the "right" answer is not as important here as thinking like a scientist.

Then the teacher engages them in some connection-making:

- Teacher: If you put your hand in a hot oven, would you want a thick or thin "coat" around it? (She draws the picture of the oven showing how it is at 400 degrees and asks the kids to compare this to their approximate range of their external body temperature on different days.)
- Devon: You'd want a thick one to help keep the coolness of your hand in and the hotter air in the oven out.
- Travis: But it is different with a coat you wear, it makes you get warm.
- Teacher: Let's think about how that happens. Pretend I left my coat outside over night in the winter so it's really cold in the morning. What happens when I put it on?

- Travis: It would feel cold. But after a while, it would warm up.
- Teacher: Where does the warmth come from? Anyone?

(no response)

- Teacher: Okay, what if I put my cold coat on a snowman instead of me, what would happen?
- Dillon: It would stay cold....
- Stacy: not if it was a black coat and was in the sun, then the sun would warm it up.
- Teacher: Okay, but if the sun wasn't out and the coat was white?
- Stacy: It would stay cold.
- Teacher: So why does it "warm up" when it's on me, but not on the snow-man?
- Sara: Your body heat!

The discussion goes on to consider body heat and energy.

Realizing that the students need to see that ultimately thermal equilibrium is reached and that insulation cannot permanently keep "what's in in and what's out out" the teacher has the students check their ice cubes throughout the day. Eventually the ones in the thickest coats also melt and the class reconsiders their theory about how coats work.

- Dillon: Well coats can't really keep what's in, in and what's out out, after a while the warmth gets in.
- Sara: It's like the coat slows it down but it still happens.
- Teacher: What still happens?
- Sara: The ice cube melts. The outside and inside get to be the same temperature.
- Travis: The hot takes over the cold.

[Notice that some of the students think of hot and cold as entities and other students are beginning to speak in terms of reaching thermal equilibrium. The class will revisit concepts of thermal energy throughout the year and it won't be until the students have learned about the nature of energy and the particulate nature of matter that they will come to a yet deeper understanding of what insulation does. With older students, a natural extension would be to talk about heat transfer processes: convection, conduction, and radiation, and how the ice cube is impacted by each in each case, no coat, thin coat, and thick coat.]

In the next few days, the teacher gives the students as individuals another opportunity to think about the question. She has them design a better ice cream cone, one that will insulate well between the temperature differential between the hand and the ice cream. The reason for doing so is that she knows that some children may have changed their ideas based upon the ice cube experience and some children may see it as one isolated instance.

Note: This example borrows from concepts in a curriculum unit developed by ESS on heat and temperature. The particular modifications and examples given draw from the work of Tina Grotzer and students in the Burlington Public Schools, Burlington, MA.

Points for Practice

•Questions that interest young children will sometimes lead them into phenomenon they can't understand deeply. Encourage them to see that they will continue to revisit questions throughout their lives.

•Try to focus the most time and attention on questions that students can grasp with a fair amount of depth.

•Communicate to children that there are connections between questions.

•Create opportunities for students to explore the efficacy of their theories in different instances.

•Attend to group and individual understandings.

•Sometimes it takes careful planning in order to gain the most information about each. Group responses influence individual responses.

•Provide multiple opportunities to rework and rethink concepts.

•Students may not realize that they already have experiences that connect to the new question in some way. Help them to see the connections.

• Some children are more reticent than others at letting you know what they're thinking. Try to get at what is really in their minds.

•Give children the opportunity to reveal and discuss their personal theories.

•Watch out for sophisticated language that can conceal children's real understandings.

•Seek a balance between determining that a certain avenue to understanding is over children's heads with offering them early experiences that will lead to understanding of the concept.

•Bolster early understandings by coming at them in a number of different ways so that the children are not dependent upon means that are developmentally challenging as their sole avenue towards understanding.

•Be alert to instances when potential misunderstandings may be generated due to children's perceptual tendencies.

Engendering Lifelong Learners

Taken together, constructivism, inquiry-based learning, and learning the epistemologies of the sciences can lead to an entirely different attitude towards learning. No longer is science a subject that is tucked away between 1:00 and 2:00 from Monday through Friday. Instead, science is a way of living your life, a way of seeking understanding, a lens that we use to know and find out.

When learning is connected to children's questions, as in the Everyday Classroom Tools Project, it sends a clear message about who the learning is for. Children come to expect that the result of their inquiry should be increased understanding of the thing they were puzzling over and at least as often as not, a new set of questions to try to answer.

By building upon children's tendency to wonder, we help them to develop a tendency to seek out puzzles and to investigate. According to teacher and writer, Hilary Hopkins, who interviewed many different scientists, what stood out for as distinctive about their childhoods was a burning desire to know "Why?" Nourishing this desire in all children will help to encourage lifelong learners who approach their lives with the eye and heart of a scientist even if they spend their days in some other profession!

Pictures of Practice

What does it sound like to communicate messages about lifelong learning to students? Here are some examples:

- Teacher: I've always wondered about what it would be like to visit Antarctica. Last night, I watched a program on it and now I have some new questions. I'd like to learn how penguins are able to stay under the water for as long as they do.

- Student: But we already learned about volcanoes in second grade!

- Teacher: One of the wonderful things about learning is that the more you know, the more there is to know. Last year, you learned some things about what a volcano is and how it erupts. This year, we'll learn some things about where there tend to be active volcanoes and how this connects to the rocky plates on the earth. You'll have fun discovering the relationships.

- Student: What are you going to do for the vacation, Mr. Thompson?

- Teacher: Well, I've always wanted to learn about the patterns on those old cemetery stones in Concord. I'm thinking that I'll go and read them and see what different kinds I can find and if there are any books to help me understand them.

Points for Practice

- Encourage students to investigate their personal "why" questions.

- Help your students to see that they will revisit similar questions again and again in their lives, evolving increasingly sophisticated explanations.

- Encourage students to see that you as an adult continue to ask questions and to learn new things.

- Encourage students to see that their parents/caregivers continue to ask questions and to learn new things. Encourage them to dialogue with their parents about what their parents wonder about.

The Keys to Inquiry

Section II: Big Messages to Communicate Around Learning from Experience

What are the big messages that you intend to communicate to your students?

Inquiry involves risk-taking, observation is an important means for learning, keeping records helps in exploring and sharing patterns, interpreting patterns involves seeking evidence while looking out for discrepancies, inquiry through our experience is part of a history of sense-making, and our questions evolve to become more expert over time.

Inquiry Involves Risk-Taking

Asking questions involves taking risks. How can you communicate this big message to your students and help them take risks in their learning? What does this mean in a concrete sense? There are at least three areas where teachers can help students learn to feel comfortable taking risks in their thinking: 1) The environment must support risk-taking in learning; 2) The curriculum needs to allow for some uncertainty and ambiguity about exactly what children will learn; and 3) Students need opportunities to learn forms of thinking that embody risk-taking and openness.

1. The environment needs to support risk-taking in learning.

Contrast the following two classroom scenarios. Which one encourages students to engage in more risk-taking? What is happening in one classroom as opposed to the other and why does it encourage students to take a risk?

> **In Mrs. B's room**, the students are working to find the answer to a science mystery from a book on science riddlers. It's a who-dunit sort of mystery and students are to read the information carefully to piece together what happened. Sean heads up to Mrs. B's desk. "I think I know what could have happened. It looks like the prints are headed into the swamp and that the strange animal is a swamp dweller. But it could be that the animal has feet that are really different from ours so it was actually coming out of the swamp." Mrs. B responds, "No, that's not it. You need to go back and reread what it says more carefully." She sends him back to his seat and then looks to the class, "Class, in finding the answer it's important to think about what really could happen, not to come up with far-fetched ideas that proba-

bly didn't happen." About ten minutes later, she canvasses the class, "Who has figured out the answer?" One team enthusiastically waves their hands in the air. She calls on them and they give an answer. "That's it, you've got it. Would you explain how you got it to the rest of the class?" says Mrs. B.

In Mrs. C's room, the students are working to find the answer to a problem that they've found in their classroom. Just about every day around the same time, a spot of sunlight appears on the floor of the classroom. The students wonder where the light is coming from. They're investigating possible sources for the light. The students offer possible explanations for the patch of light. "I think someone could be shining a flashlight into our room," says Mike. "Maybe the decorations on our windows make it so the light comes in at that spot" offers Sara. Mrs. C. says, "Let's write these ideas on the board to help us remember all of them" as she begins a list. "Maybe somebody in our room is doing it and they're trying to trick us, " says Tommy. The class begins to laugh. "How could they trick us without our knowing about it? laughs Paul. Mrs. C reminds the class that when brainstorming, it's important to explore lots of different possibilities and that even ideas that sound impossible to us may not be or may lead us to new ideas about what happened. She lists the idea on the board. After the class has a long list, Mrs. C. asks how they could narrow it down. Amy says, "Well, we know it only happens when the sun is out, so that makes some explanations more likely than others. "It sounds like we should think more about when it happens and exactly what happens," says Mrs. C.

Inquiry-based learning requires an environment that supports risk-taking.

This means that:

- question-asking is invited.
- "mistakes" are valued for the learning they provide and as natural parts of the inquiry process.
- open-ended questions are asked and appreciated.
- there's more than one possible answer.
- theorizing and considering evidence is considered more important than a "right answer."
- sometimes questions are asked and not answered.
- all ideas are okay to share.
- ideas are discussed for their explanatory potential, ability to solve the problem, and the thinking that they inspire as opposed to being called "good" or "bad," "right" or "wrong."

Teacher Response

Teachers in the Everyday Classroom Tools Project were asked what kinds of things they could do to create an environment that is conducive to inquiry. Here is some of what they had to say:

"ask open-ended questions."
"set up situations where children are asked to observe and predict."
"take a "how could we find out" approach to kids' questions."
"use the outside environment as a starting point for questions and observations."
"model "what if?" situations.
"encourage sharing ideas (all welcome)"
"validate and respect student responses (for instance, list them on a chart)"
"be non-judgmental"
"welcome questioning"
"model inquiry (as a teacher)"
"ask, don't tell"
"create a 'holding environment.'"
"make time to explore and observe."
"create a positive atmosphere with encouraging words and actions."

It is also important to help your students understand the rationale behind the things that you and they do to support risk-taking in learning and thinking. In the context of classroom discussion, make a point of explaining that we respect many different ideas to encourage everyone to get involved, to think through problems, and to separate critiquing from generating concepts. Understanding that certain types of environments inspire good open-minded thinking in science will help them to go off to seek out and/or recreate such environments when they are adults.

2. The curriculum needs to allow for some uncertainty and ambiguity about exactly what children will learn.

One of the puzzles for teachers around inquiry-based learning is that they worry about what content children will learn. The learner-directed nature of inquiry-based learning means that teachers can't dictate learning outcomes as much as they may have with more traditional curriculum. This bit of uncertainty raises concerns for some educators and parents.

What should teachers do? Well, first of all, it's important to realize that there are lots of ways to come at teaching the same set of underlying science concepts. Of the many questions that children ask, there will be a whole set of them related to evaporation and condensation, for example, or to weight and density, for another example. By deciding which questions to pursue with greater depth, teachers do have the ability to choreograph learning to a certain extent.

It's also important to realize that there’s a trade-off in part because students are learning so much more than content. They are learning how science is conducted.

This provides them with tools that will serve them throughout their lives even when the content knowledge that they have learned has become outdated.

At its best, inquiry-based learning starts with children's questions and their prior knowledge and experience. A wealth of learning research underscores the importance of starting with what children already know in helping them build new understandings. Sometimes this means that teachers find themselves faced with more basic questions than the curriculum objectives they hoped to achieve. So, should teachers address these more basic questions or those called for by the curriculum? The choice here is very clear based upon what we know from research on learning. Without understanding the more basic questions, children can't develop an understanding of the more complex ones. This does not mean reducing question to neat little chunks. It means grappling simpler question before more complex ones.

In order to learn to understand concepts deeply, students must have a conceptual framework to fit the information to. Learning can be thought of as constructing increasingly complex networks of connections and understandings. If we teach concepts and facts that are isolated from students other knowledge, they will have little basis for understanding it and remembering it.

It's not only important to start from what kids say they know, it's important to probe those understandings and make sure that kids really do understand what they think they do.

3. Students need opportunities to learn forms of thinking that embody risk-taking and openness.

There are different modes of thinking and these modes map onto to different problem types to help us think well in a variety of situations. Researchers David Perkins and Shari Tishman refer to seven different thinking dispositions and the sensitivities, skills, and inclinations that are associated with each. At least two of these relate to the open-ended forms of thinking: 1) The disposition to be broad and adventurous and 2) the disposition towards wondering and problem-finding.

A description of each form of thinking is provided below. Each form of thinking has a set of key moves defined by Perkins, Tishman, and colleagues. Additionally, a set of prototypical questions can be associated with each key move. The key moves and questions are given for each disposition.

A. ***The disposition to be broad and adventurous refers to the tendency to be open-minded, to generate multiple options, to explore alternative views, to have an alertness to narrow thinking.*** Its purpose is "to push beyond the obvious and reach towards a richer conception of a topic or a broader set of options or ideas" according to Tishman and colleagues.

Key moves:

This means helping students to ....

- ...push beyond the obvious and seek unusual ideas.
  - How else can we think about this?
  - Is there anything else we can do?
  - What wacky and unusual ideas can you come up with?
- ...see other points of view. How would ________ think about this?
  - What if you were on the other team, what would you think?
  - If you were looking at it from where a bird is what might it look like?
- ...look for opposites, things that are contrary.
  - What is the exact opposite of the way we are thinking about it?
  - What if we thought about it in an opposite way?
- ...challenge assumptions. Is there anything that we are taking for granted?
  - Are we sure that we have to do it this way?
  - What if we tried to get the kite to come to us instead of us trying to get the kite?
  - Are we creating any "rules" that aren't really rules?
- ...explore new territory, go beyond the boundaries.
  - What if we change the way that we think about the problem?
  - Are we using the most open-ended wording of the question?
  - What are some other ways to think about this that we haven't tried yet?

B. ***The disposition toward wondering, problem-finding, and investigating:*** The tendency to wonder, probe, find problems, a zest for inquiry, an alertness to anomalies and puzzles, the ability to formulate questions and investigate carefully. Its purpose is "to find and define puzzles, mysteries and uncertainties; to stimulate inquiry" according to Tishman and colleagues.

In addition to helping students use these forms of thinking in their school science, encourage them to use these forms of thinking on their own in their every day lives. It's important for them to see how thinking in the ways outlined above leads to noticing something of interest or brings them to a deeper understanding. Linking the form of thinking to an improved outcome increases the chances that students will engage in the thinking on their own.

Key moves:

This means helping students to...

- ...to be curious! ...to wonder about things! What do you wonder about this?
  Are there some things that you want to know about it?
  What questions do you have about it?
- ...to find problems, questions, and puzzles. Is there anything that seems odd to you?
  Is there anything that you want to fix?
  Why do you think the writer, artist, etc. did that?
  What would you change if you could?
  How would you make it better? ...different?
- ...seek out what's hidden or missing. Do you notice anything that seems to be missing?
  What would you add if you could add something? (Why do you think it's not there?)
- ...to play with what if? questions.
  What if ______________? (...there were no gravity? ...there were no rules? ...dinosaurs never existed? ...we didn't have any numbers? ...it didn't get dark at night?)

 "Key Moves" developed by Shari Tishman in conjunction with The Patterns of Thinking Project. The project was supported by the MacArthur Foundation through a grant to the Co-Principal Investigators, David Perkins and Shari Tishman. "Sample Questions" developed by Tina Grotzer.

Observation is an Important Means for Learning

What does it mean to really *look*? Is there a difference between looking and *seeing*?

These are good questions to ask your students. Their responses can help introduce explicit discussion on the how we observe the world around us and how sometimes we don't.

Often when you ask students these questions, they respond with statements like:

> "Well, you can look at something and not really see it."
> "Seeing can mean that you actually study it and think about what is there."
> "Sometimes you can look at something and even if you try, you just can't see what is there, like when a caterpillar is camouflaged."
> "When you really look at something, you notice details that you otherwise wouldn't see."

In order to help students think about what it means to look and what it means to really see, ask them to try to visualize the following in their minds and see how they do:

1) What does the face of a penny look like? Try to visualize all of the details.
2) Does the clock in your kitchen at home have anything to mark off the minutes between the numbers? If so, what is it (dots, lines, etc.)? Does it have second hand? If so, what color is it?
3) What brand of tires is on your bike?
4) What color is the front of your school? If the school is brick, what is the pattern like?
5) How are the knobs laid out on the front of your TV set?

Students often find these questions hard to answer, even thought they seem fairly straight forward. Why is this the case?

Much of our cognition is pattern-driven. This has both benefits and drawbacks. We need to be somewhat selective about what we pay attention to or our world would be overwhelming to us. Beyond this, attending to certain kinds of patterns is more efficient than others. For instance, noticing the relationship of the hands on the clock to each other is probably much more helpful to us than noticing the color or form of the markers between the numbers. At the same time, our tendency towards efficiency can also keep us from noticing certain patterns in our world. It can keep us from noticing and thinking about everyday patterns that are all around us.

1. We can learn a lot by noticing what goes on around us.

The difference between looking and seeing in the exercise above really comes down to "active processing." When we actively process information around us by perceiving it and reflecting upon it, we are much more likely to notice patterns, to make connections to other things that we know, and to develop an appreciation for what we are looking at. Stopping to reflect can lead to noticing puzzles and deepened understanding. It's important to help students understand the importance of noticing patterns and to experience the rewards of doing so.

2. Noticing patterns is a first step in asking why certain patterns exist and why there are certain puzzles or oddities in patterns.

As we start to notice patterns, we also begin to notice puzzles to be explored in the patterns. These puzzles can lead to a deeper understanding of our world. For instance, in the Everyday Classroom Tools Project, students are encouraged to begin to notice different patterns that are related to the seasons. As they start to notice these patterns, they uncover puzzles that reveal areas that need investigation in order for the students to understand them.

3. We need to try to think openly about what we experience, remaining alert to tendencies or "lenses" that may be limiting.

We need to try to keep our thinking as flexible as possible and not get stuck in one way of seeing something. This is discussed further below under the idea, Interpreting Patterns Involves Seeking Evidence while Looking for Discrepancies.

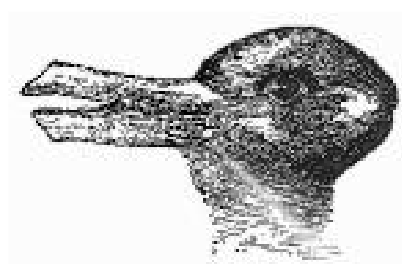
Even when we are trying to remain open in how we observe, there are certain obstacles that can get in our way. For instance, what do you see in the two drawings below?

If you see an old lady,
can you also see a young lady?

If you see a young lady,
can you also see an old lady?

If you see a rabbit,
can you also see a duck?

If you see a duck,
can you also see a rabbit?



Keeping Records Helps in Exploring and Sharing Patterns

Keeping records of our observations can help us to explore and understand patterns as well as share and discuss them with others. Drawing upon tools can extend our ability to detect and share patterns. Each point is explored in turn.

1. Keeping records can help us to explore patterns.

Keeping records of experiences can help in detecting patterns. Not all patterns in the world occur close enough in time that we can detect them just by looking. In addition, micropatterns and macropatterns can sometimes tell a very different story. Keeping records of events can help us to notice patterns over time and in broad and small scale. For instance, if we were to observe the weather in a given area for a week in the summer, it is possible that we would decide that a given area has very dry and hot weather. If we expand our looking by keeping records over the course of a year, we may see that at certain times the weather is very wet while at other times, it tends to be drier. If we extend our looking by keeping records (or looking at kept records) over the course of a number of years, then we might see quite different patterns.

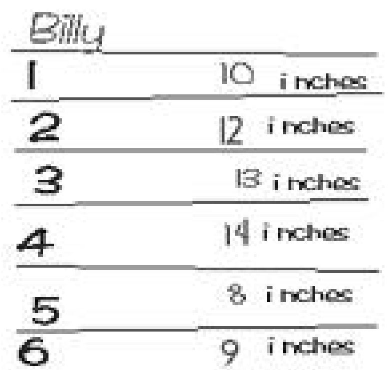
One of the reasons why it is so important to help children keep records to explore patterns is because their sense of time is different from adults. Our understanding of our experiences is relative to our other experiences. You might recall that as a child, summer vacation seemed to last forever whereas now it just flies by. Relative to how long you had lived as a child, summer vacation WAS a long time. So what seems like a long time for a pattern for children is quite different from an adult perspective.

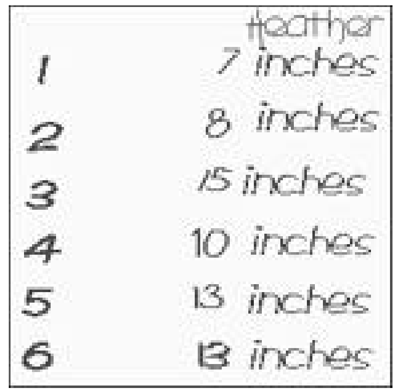
Time helps to create context. We sometimes take the context of our experiences for granted until some child asks a question which reveals that we hold a different context than he or she does. Questions like, "Were there refrigerators when you were a kid?" or "What was the cold war?" remind us that we interpret our experience through the context of earlier experiences. The blizzard of '78 is ancient history to kids, but part of our recent memory. Long-term knowledge of weather patterns accumulates to provide a rich context in which to interpret information that we receive from the environment. We've experienced a different set of extremes and have a greater sense of norms.

Teachers who focus on inquiry-based learning need to keep these differences in mind. In so doing, teachers can help children use tools to facilitate pattern-finding in their experiences (charts, graphs, journal entries, etc.) Teachers can also help children learn to look at records of patterns charted by others. This invites students to benefit from the experiences of others--to learn from a rich history of accumulated knowledge of patterns. The sharing of patterns, both those students find and those that others have found, is where we turn next.

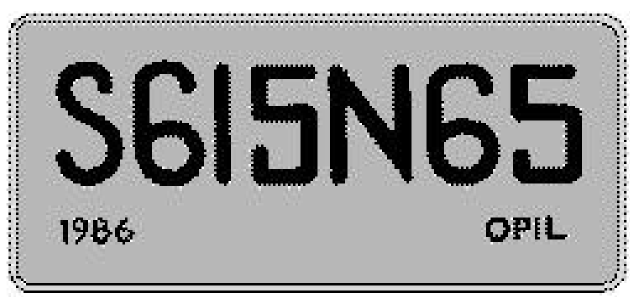
2. Recording patterns makes it easier to share and discuss them with others.

We may sense that a certain pattern of events is occurring or has occurred. By recording our observations, we amass evidence that helps us to detect the pattern and to share the pattern with others. This is particularly important in classrooms using mediated constructivism as a means to advance knowledge. The collecting of evidence allows individual learners to detect patterns and to construct understanding of them, and it provides a means to share them with others such that the community of learners benefits from the collective experience of those in the group.





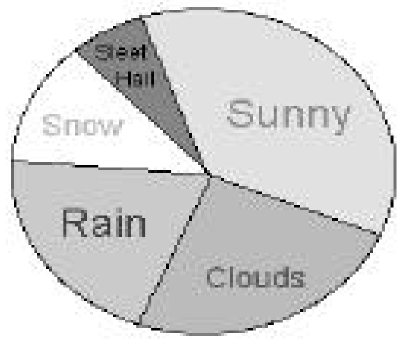
Sharing recorded patterns with others also invites consideration of discrepancies in the patterns that individuals find. Scientists record and share their data with others. This invites discussion, opportunities to notice discrepancies between data sets, and to seek and evaluate reasons which help to explain the discrepancies. Often this process points out differences in how data was collected and highlights variables that need to be taken into account. For instance, one student may have collected the shadow data in Figure 1 while another student collected the data in Figure 2. A priori, the students may not have had a clue that they needed to also attend to what time in the day they collected their shadow lengths. However, by looking at the discrepancies between the data they collected, they can construct an understanding of the importance of the variable, "time of day."



Sharing recorded patterns with others invites consideration of the best mechanisms by which to communicate specific patterns. Different types of graphs emphasize different aspects of patterns and thus the choice of graph is a decision about how to communicate one's experience to someone else. For instance, the two graphs below emphasize different

aspects of the same form of data--information about rainfall. One graph is intended to emphasize the types of weather relative to other types (the pie graph) whereas the other (bar graph) stresses the seasonal variation in rainfall. Deciding how to present patterns to others involves students in thinking about what it is that they wish to communicate about the pattern.

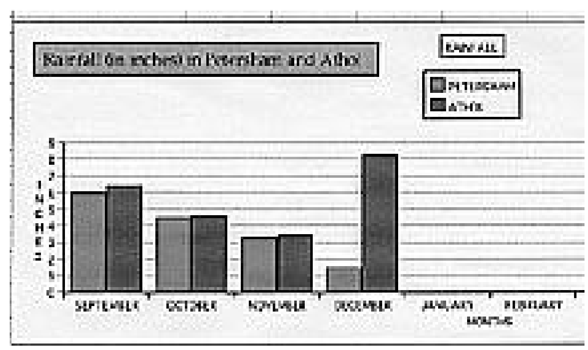
Invite your students to share their data visually and verbally. Provide a safe and supportive "scientific community" where discrepancies in data sets are viewed as scientific questions to be investigated, not errors--but steps on a path of closer approximations to scientific "truth."



3. Tools can help in finding out about patterns.

Not all patterns reveal themselves to us through our direct observation. Tools can help us to see patterns that we otherwise would not see and to learn about the patterns that we do detect in ways that we otherwise wouldn't. Classrooms need to help students view tools as perception-extending devices.

Tools come in many forms. There are actual mechanical tools that serve as aids to perception. For instance, the telescope is a tool for extending vision. The magnifying glass or microscope extends vision in another way.



The internet can be viewed as a special kind of tool of this type. It belongs in a class of tools that extends our ability to experience and share our experiences more broadly. Through the internet, we can extend our sense to know that it is night in Japan when it is daylight in Ohio or that it is winter in Australia when it is summer in New England.

Beyond these actual mechanical tools, are tools that transform patterns in a more abstract sense. For instance, statistical transformations can be viewed as tools that allow us to see patterns in transformed data that were not so accessible to us in the raw data set. Our number system can be viewed as an ingeniously designed tool. For students, these types of tools are probably best understood in the "tool sense" by drawing analogies to concrete tools students are probably more familiar with.

Interpreting Patterns Involves Seeking Evidence While Looking Out for Discrepancies

One of the primary goals of the Everyday Classroom Tools Project is to get students to notice patterns in their experience and then ask "why?" The goal is to encourage them to go beyond describing and seek to explain. At this point, they move from pattern noticing to hypothesis building. In some sense the distinction is a false one because many scientists hold an a priori notion of what might happen in their heads and seek patterns that confirm or disconfirm it. In any case, the pattern noticing doesn't stop because even after scientists notice a pattern and formulate a hypothesis about it, they continue to seek patterns in a confirmatory or disconfirmatory mode.

Formulating a hypothesis is when you consider what you think might be happening and seek reasons for why you think it might be happening. It is an attempt at interpretation or explanation.

One of the potential pitfalls of formulating a hypothesis is closing off one's mind to alternative explanations. It is important to gather evidence in support of a hypothesis while keeping an eye out for disconfirming evidence, puzzles that can't quite be explained by the present interpretation. Keeping an eye out for potential "cracks" will help your students to evolve the best explanations and to understand that science involves the purposeful discard of theory as better theories come along.

Interpretation involves reasoning about and evaluating evidence. Research shows that students don't necessarily evaluate evidence well on their own. There are certain types of problems that they run into. For instance, it is not uncommon to only consider evidence on one side of a case, to make unwarranted claims, or to not notice when claims are unwarranted. Therefore, it's important to help students learn to think well about evaluating evidence and to help them learn to do so.

At the end of the Keys of Inquiry is the Evidence Evaluation Poster which you may consider photocopying to poster size.

Inquiry Through Our Experience is Part of a History of Sense-Making

Often when teachers begin inquiry-based learning with their students, they help their students to
discover the importance of on-going inquiry in a broader sense. They invite their students into the company of scientists and sense-makers throughout history who have sought to understand the world that we live in. There are a number of important lessons that students learn.

1. We are still finding out how the world works. We don't know all the answers.

When science class only consists of facts and figures that we know to be "true," it communicates to students that we know all the answers, instead of letting them know that our ignorance far outweighs our knowledge. It keeps them from finding out that there are lots of mysteries that we can't begin to answer. Letting students in on the mysteries of the world ignites their curiosity and opens the door to a lifetime of finding out. In the late 1980s into the 1990s, NASA conducted the Space

Seeds Program in which they invited school children across the nation to participate in a grand science experiment in which students compared seeds that had been in space to seeds that served as a control group here on Earth. One of the many wonderful things about this project was that it communicated to children that there are questions we don't know the answers to and that they can participate in finding out.

2. For centuries, people have tried to understand the world and make sense of it based upon what they could perceive.

Often the theories that students evolve as they first grapple with explaining different phenomenon are not unlike those that ancient (and not-so-ancient!) people created to explain similar phenomenon. This is a common enough occurrence that it is referred to as "recapitulation" or "ontogeny (individual growth) recapitulates phylogeny" (our collective growth). Often the basis for the similarities has to do with certain ways of seeing and measuring information. Certain perceptual information seems to lead to certain conclusions. For instance, it does appear that the moon follows you when you walk. Thus young children think the moon is following them, and are basing their knowledge on what they see just as people did centuries ago. With a balance of constructivism and scaffolding we can help students see the common sense of their intuitive theories while we help them to reach towards more current day scientific notions based on our collective knowledge and the tools and techniques we have available to us today.

Today, we continue to create theories about the world and try to make sense of what we observe. It is important to continue to visit and revise those theories as we learn to ask increasingly sophisticated questions.

Our Questions Evolve to Become More Expert Over Time

Research shows that experts and beginners tend to notice different kinds of patterns when they consider scientific phenomenon. Experts structure their understanding and construe meaning from information differently than beginners. Experts tend to notice patterns related to deep structure while novices tend to notice more superficial features or may get drawn to those features that most attract their attention whether or not these are the patterns that are most relevant. Experts tend to consider the bigger picture and to notice larger, systemic patterns. Experts also tend to monitor their activity in a self-regulatory way.

A novice looking at weather patterns might consider the localized effects of warm and cold fronts and the weather implications of the fronts meeting, while an expert might look beyond the immediate patterns to consider how they are linked in a complex causal relationship with weather patterns such as El Ninio or with the patterns of flow in the Gulf Stream. Experts are also more likely to contrast their explanation of what is happening with commonly accepted theories to see if it complements or contradicts those theories and whether they have considered the right set of variables to know.

This finding is certainly not surprising considering that experts have contextualized knowledge, background information that helps them decide how to attach importance to particular findings. Indeed as someone becomes expert in a given domain, their manner of attaching importance to patterns undergoes a shift. This is referred to as the "novice-expert shift."

What does the "novice-expert shift" imply for inquiry-based science? Students need opportunities to revisit questions and concepts as they spiral towards increasing expertise. Students' early questions will be those of a novice and only as students seek answers to their questions and gain in expertise will their questions become increasingly sophisticated and focused on the deep structure of the knowledge in the domain that they are studying. This doesn't mean that teachers can't scaffold students' question-asking to some extent. However, teachers should not scaffold students beyond the level at which the questions make sense to the student and generate from what the student believes is sensible to ask.

This argues for giving students plenty of time to delve into topics deeply. If students are not given sufficient time to delve into a topic, they will merely inquire at the surface of the topic and never reach the more meaningful patterns and understandings to be constructed at deeper levels.

Communicate the process of increasing expertise with students by letting them know that:

- Once you've learned certain things, your questions change.
- One question may take you part of the way towards understanding, then you often need to ask a new question.
- Deeper questions often come from earlier questions.
- Atsomepoint,thingsconnecttootherthingsthatweknow.Trytofindconnections to help you better understand both what you are learning and what you already know.
- Identifying relevant questions is a process. It is fruitful to pursue asking a next and more sophisticated question.

Evidence Evaluation Point!

Consider the evidence carefully
by asking yourself some questions:

1. Where does the information come from?

- What observations can *you* make?
  (directly from looking at the evidence or from seeing something happen)
- Think about possible sources of bias or error.
- What information comes from *other sources*?
  (from other people by what they say or have written)
- Think about possible sources of bias or error.
- Think about how credible the source is.

2. What patterns can you see in the evidence?

- Think about whether you are making any assumptions.
- What do you know for sure?
- What do you think might be true?
- Think about whether there are any missing links in your logical argument for what you know is true and what you think must be true.
- What information do you need to fill the missing link?

3. What is the most <u>plausible</u> explanation based on the *current* evidence?

- Consider what you know for sure.
- Consider what information you still need.
- Ask yourself: Does the situation require being certain beyond the shadow of a doubt? Or is a good theory acceptable?

Table reprinted with permission from Materials for Integrating the Teaching of Thinking: Developed for the Burlington Public Schools

Telling Time without a Clock:

Scandinavian Daymarks

How would we measure time without a clock? We know that the Sun moves across the sky during the day. Can we tell what time it is by looking at the position of the Sun?

In modern times, precise time measurement is very important. So many people depend on knowing the "right time" to go about their daily business. Industrialized societies need accurate regular time measurement to function. Does everyone on Earth live in such a society? No, in some parts of the world people still live much as they did thousands of years ago. Even our industrialized societies are fairly new when compared to most of human existence. Only a few hundred years ago telling time exactly wasn't so important. But it was still helpful to get a rough idea of what time it was.

Pointing at the Sun

Probably the simplest way to tell time is by knowing the path of the Sun across the sky and how long it takes the Sun to move. Where on Earth is this method easiest? If the Sun rises high in the sky and its path doesn't change much from season to season, it is pretty easy to tell time from the position of the Sun. The Sun behaves more like this the closer to the equator one gets. Many pre-industrial peoples in the tropics used this method of telling time, even into this century. Many African peoples—such as the Cross River, Caffres, Waporogo, and Wagogo peoples—would indicate time by pointing to a place in the sky where the Sun would stand at the time they wished to indicate. The same method was used in other parts of the world, such as the New Hebrides, Dutch East Indies, and Sarawak.

Hours of Day, Hours of Night

What about telling the time of the Sun in regions farther north or south of the equator? The Sun's path changes much more over the course of the year as one moves farther from the equator. In winter the Sun might be very low while in summer it might be much higher.

One simple way to tell time was to divide the daylight time and the night time into segments. Many cultures did this, using different numbers of segments. For example, the Chinese divided one sun-cycle into 12 sections and the Hindus into 60. Very early on, the Egyptians divided the period between sunrise and sunset into 10 sections, and then added two more sections for the periods of twilight at dawn and nightfall—making 12 sections of daylight time. They then divided the night into 12 sections also. This made a division of the sun-cycle into 24 sections, very much like the 24 hours that we divide the sun circle into. The Babylonians used a similar system, and this is in fact where our modern 24-hour day has its origin.[1]

However, there was an important difference between the hours we use and the "hours" of the Babylonians and the Egyptians. Their "hours" changed length, depending on what time of the year it was! They divided both daylight and nighttime into 12 sections each. When the daylight lasted a long time during the summer, their daylight "hours" could be as long as 75 minutes, while the nighttime "hours" were only 45 minutes long. In winter, however, when the Sun was not up as long, their "hours" might shrink to as short as about 55 minutes during the day, while at night they were about 70 minutes. Only on the equinoxes were their "hours" 60 minutes, both day and night, just like our modern hours. You can imagine what trouble using a system like this would cause in the modern world, as the length of the hours changed slightly each day of the year!

The ancient Greeks had borrowed the Babylonian/Egyptian system of counting hours, but in the late second century BCE, over 2100 years ago, a Greek astronomer called Hipparchos suggested that the "equinoctal hours" of 60 minutes each for use at all times of the year. This is where our modern system ultimately comes from,

1. The English word “hour” comes from Middle English *houre*/*oure*/*ure*. These forms were borrowed from Anglo-Norman *ure*, itself related to Old French *ore* or *oure* (Modern French *heure*) stemming ultimately from Latin *hora*. Late Latin *h* had become a silent letter, explaining why it does not appear in the older English or French words for “hour”—it was only added back in modern times, modeled on the classical spelling of Latin *hora*. The Latin word stems back to a very ancient Indo-European root, *jér-* or *jór-*, which had to do with units of time. This same root lead ultimately to the word “year”, through a different developmental path.

but it was a long time before it became widely used. The Greeks (and Romans) continued using the Babylonian/Egyptian system of "temporal hours" which changed length through the year for thousands of years, and many European peoples adopted this usage as well. In 725 CE, the English monk Bede wrote a highly influential book on time-keeping. Most importantly, it helped popularize the modern Western system of counting years (AD/CE and BC/BCE), but in it Bede also argued for dividing the sun-cycle into 24 equal hours at all times of the year. Nevertheless, it was not until mechanical clocks started to become common during the 1300s that the "equal hours" began to replace the "temporal hours" for good.

Scandinavian Daymarks

The Egyptians, Babylonians, Greeks, and Romans all lived far enough north of the equator that they could not rely on a fairly constant Sun-path over the year, as people in the tropics did, but they were not so far from the equator that the differing lengths of day and night made it difficult for them to use their "temporal hours", even though their lengths changed somewhat over the course of the year.

Very far north (or south) of the equator, however, the difference between the length of daylight time in the summer is very much greater than in the winter. In parts of Scandinavia above the Arctic Circle (at a latitude of 66.5° North) the Sun does not set at all for part of the summer—it is daylight all the time. On the other hand, for part of the winter the Sun does not rise in these same areas. Obviously there is no point in dividing the daytime or nighttime into twelve sections if they are not taking place! Even if the Sun sets for only three of our modern hours in the summer, if one is dividing the daytime and nighttime into Babylonian/Egyptian-style "temporal hours", the nighttime hours will be so short compared to the daytime hours that there is hardly any point in making the divisions.

However, even very far north (or south), no matter where the Sun rises or sets, the middle of its path is above about the same part of the horizon. That means you can always tell when the middle of the day is if you know above which point on the horizon the highest point of the Sun's path is. Also, no matter how high the Sun is above the horizon, it always passes over the same points on the horizon after the same interval of time. Using these facts, the people living in Scandinavia developed a system of time-keeping quite different than the Babylonian/Egyptian system.

As said earlier, our modern system of time-keeping divides each sun-cycle into twenty-four hours, each of which is 60 minutes long. The Scandinavians divided each sun-cycle (*sólar-hringr*, "sun-ring" in their language) into eight sections.[2] They did this by dividing the horizon into eight sections (north, northeast, east, southeast, south, southwest, west, and northwest). Each of these sections was called an **eighth** (*átt* or *eykt*).[3] A place on the horizon which lay dead center in any of these eight directions (due north, due northeast, etc.) was called a **daymark** (*dagmark*).[4] The identified the time by noting when the Sun stood over one of these daymark-points on the horizon.

The Midday Daymark

What do you think the most important daymark was? It was the daymark beneath the highest part of the Sun's path, since the Sun reaches the highest part of its path above the same part of the horizon every day of the year. This central daymark was named Highday or **Midday** (*hádegi* or *middag*). That was the name of the time, just as we would say "twelve o'clock" or "noon". The position of the Sun at this time had its own related name: **Midday Place** (*hádegista_* or *middagsstad*)[5].

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2. For convenience, all Scandinavian terms are given in Old Norse (or Old Icelandic), the medieval language from which the modern Scandinavian languages are descended. The equivalent terms in the modern Scandinavian languages have changed very little. Geographical names, however, are written in the language of the named feature's region.

3. As a translation of *átt*, a word like “octant” or “octet” might be more appropriate than “eighth”. Since the relation of these words to the number eight (8) might not be immediately apparent to students, “eighth” is probably better. It might be mentioned that sometimes this word is spelled *ætt*, which means “family” (used in the sense that the different directions may be grouped into a “family of directions”. It is unsure which term is more correct, but *átt* and “eighth” are used in this document.

Eykt has a totally different meaning. It is related to the English word “yoke” (Old Norse *eykr*), as in the device used in harnessing draft horses or oxen. Draft animals could only be harnessed for a certain length of time before they needed to be rested. Thus, people divided the time of day into segments according to when their animals were yoked. Eventually the *eykt* referred directly to the unit of time, rather than an actual yoking-period. [Jan de Vries, *Altnordisches etymologisches Wörterbuch* (Leiden: Brill, 1961).]

4. An alternate name is *eyktarmark*, very commonly used in Iceland. English-speaking students, however, may have an easier time remembering *dagmark* and its clear relation to English “daymark”.

Many, perhaps most, Scandinavians lived in isolated farms or villages in earlier times. They used geographical features located on the horizon (as viewed from near their homes) as guides to the daymarks. Often they would name a feature, usually a mountain, after the daymarks. Since Midday was the most important daymark, there were many mountains named after it: Middagsfjället, Middagshorn, Middagshaugen, Middagsnib, Middagsberg, and Middagsfjeld are all mountain names in Norway--similarly Sweden has Middagsberget and Middagshognan, while Iceland has a Hádegisbrekkur. All of these names are made by taking the Scandinavian words for Midday (or Highday) and adding a Scandinavian word meaning "mountain". They are like saying "Mount Midday" or "Midday Mountain" in English.

The Other Daymarks

Midday was the most important daymark, since it divided the Sun's path in half, but there were seven other daymarks in all, and each of these had names, too. Some of these daymarks took place during the night when the Sun was below the horizon. Because Scandinavia was so far north, during the winter the Sun could be below the horizon most of the time! But when the Sun is not very far under the horizon and the weather is clear, it is still possible to see it's light showing where the daymark is on the horizon.

What is the opposite of Midday? It is Midnight. Just as we have a name for the middle of the night in English, the Scandinavian's had a name for the daymark in the middle of the night: *miˇnætti*. It is very easy to find a Midnight daymark in the summer in Scandinavia. Although the Sun often does set for a while at night, the twilight is often bright enough to mark the spot on the horizon which the Sun is beneath. In some parts of Scandinavia the Sun simply does not set in the middle of summer! Then one need only look for the lowest point in the Sun's path, and mark the spot on the horizon beneath it. Just as the Sun reaches its highest point (Midday) at due south, it reaches its lowest point (Midnight) at due north.

Between Midday and Midnight are three more daymarks. The first is called **Undorn** or simply *eykt*. The names for this daymark are hard to translate into English. Their origins were lost long ago, and even the ancient Scandinavians may not have known exactly where the names came from--only that they referred to this time of day in the afternoon.[6] After the Scandinavians were converted to Christianity, they some-

5. The character ˇ is pronounced like the "th" in words such as "this" or "bathe". It was originally invented by English scribes and was used in writing Old English. It was later adopted by Scandinavian scribes, but eventually fell out of use in English writing.

times used the name *nón* for this time, borrowed from the Latin term *hora nona*, which means *ninth hour*—the Roman people, who spoke Latin, had considered the ninth hour of the day to happen in the afternoon (clearly they started counting their hours at a different time (6 a.m.) than we do now!).[7]

After *undorn/eykt* (or *nón*) comes **Mid-Evening** (*miˇr aptann*). At Mid-Evening, the Sun is approximately due west--or halfway between the Midday (south) and Midnight (north) daymarks. On the equinoxes the Sun would set right at the Mid-Evening daymark. Before Midnight, there was one more daymark called **Night-Measure** (*náttmál*).[8]

Between Midnight and Midday there are three more daymarks, making eight in all. Midnight was followed by **Ótta**. This name comes from an very ancient Germanic root-word, **uhtwón*, and designated the time of night before daybreak, which was thought the deepest and most frightening time of night.[9] Even during summer, the sky would darken a little at this time in many parts of Scandinavia. In winter, Ótta must have seemed very dark indeed!

Mid-Morning (*miˇr morgun*) took place when people woke up in the morning.[10] Most of the daymarks were determined by events in daily life like this. Since the Sun rose so early in summer, it might have been light long before people finished sleeping. On the other hand, in winter, the Sun might not rise until long after people woke up. In a way similar to that of Mid-Evening, the Sun at Rise-Measure is approximately due west, halfway between the Midnight (north) and Midday (south) daymarks. On the equinoxes the Sun would rise right at the Rise-Measure daymark. Before Midday there was one more daymark called **Day-Measure** (*dagmál*)—just as Night-Measure came before Midnight.

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6. For a discussion of *eykt*, see note2 above. The Norwegian word *ykt* or *økt* (which is descended from *eykt*) is often used to refer to lunchtime meal eaten at this time; perhaps if this time of day was a popular lunch break, the general term *eykt* stuck as a special name for this time.

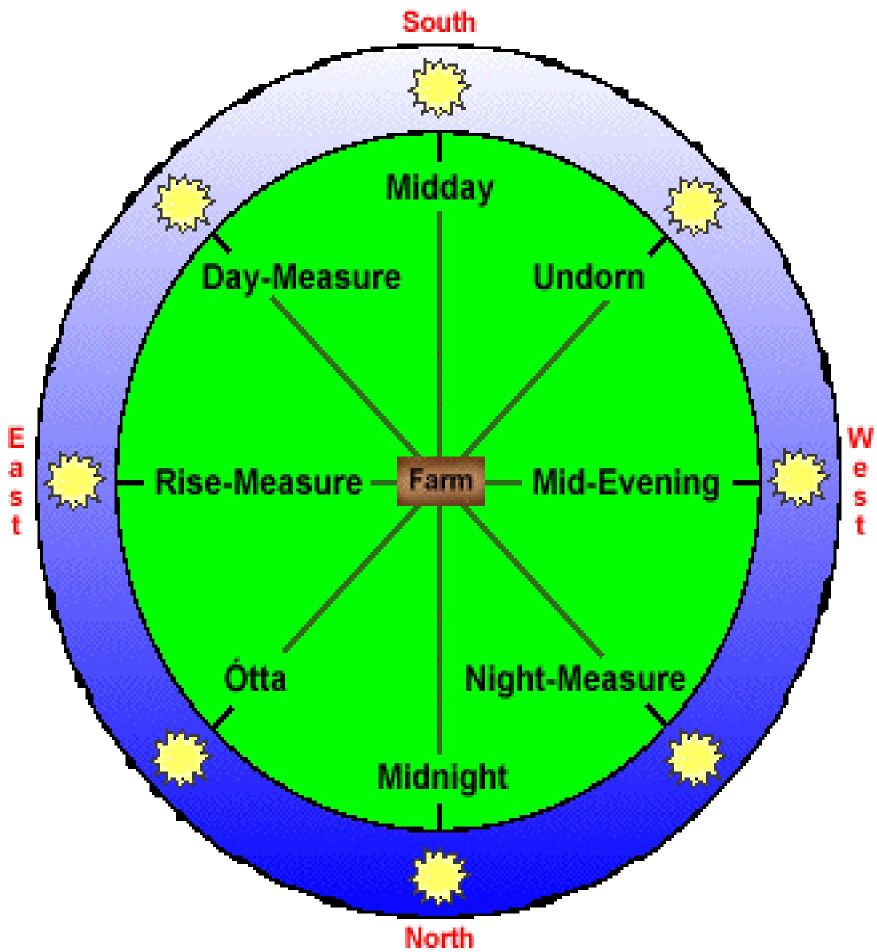
The term *undorn* may have also referred to a meal. There was once a term "undern" in English, though the word largely fell out of use after the 1400s. Strangely, it could mean either a time in the morning or (like the Scandinavian *undorn*) mid-afternoon. Variants survived in northern British English dialects (in forms like "oanders", "aunders", and "andrum") meaning "afternoon meal" into the late 1800s. In teaching this material, "undern" could be used in place of the Scandinavian word *undorn*, if desired.

7. The English word "noon" has a similar origin, but its time has been transposed to midday! The same shift has happened to Dutch *noen* and French *none* (a somewhat archaic term in French, now generally limited to use in certain French dialects). These words also come from Latin *nona* and originally indicated a time around 3 p.m., but now mean Midday.

8. The Old Norse word *mál* is translated here as "measure". It was a word which could be used with a variety meanings, mostly having to with the measuring out of a certain thing. It is related directly to the English word "meal" (as in a time for eating, or food eaten) and can be used in that sense.

These other daymarks did not seem to be as important as Midday, but sometimes we find geographical features named after these daymarks, just as we found them named after the Midday daymark: in Norway we find Rismaalsfjeld and Nonsfjeld, in Sweden we find Nonsberget and Nonsknätten. In Iceland are Dagmálahóll, Eyktargnipa, Nónfell, Miˇaptansdrangur, and Undornsfell. Around a thousand years ago many Scandinavians settled in England, and they used some of these same naming traditions at their new English farms. Thus, there are some more daymark-type place names in the parts of England where they settled.

How Daymarks Work



Here is a view of a Scandinavian farm from above. In the center is the farm house, and around it are imaginary lines and labels showing in which direction the various daymarks are. The edge of the green circle represents the horizon. Beyond it the Sun is shown standing at the eight daymark points on the horizon. Would the Sun always be visible at these daymarks? No,

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9. There is an English version of the Scandinavian word *ótta*: ughten. It is obsolete, having largely dropped out of usage after the 1300s. A Scots dialect version of it, "oachenin" was still being used in Caithness, Scotland around 1900. In teaching this material, however, "ughten" could be used in place of the Scandinavian word *ótta*.

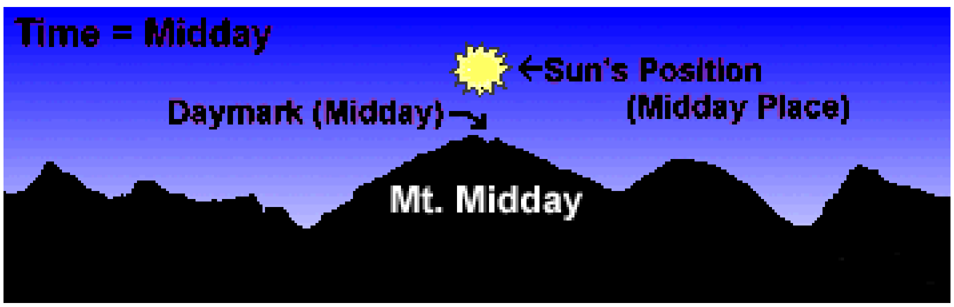
10. Another name often used for Mid-Morning was *rismál* meaning "Rise-Measure", a name formed like Day-Measure and Night-Measure

sometimes it would be below the horizon and not visible. But even when we cannot see the Sun it is still below the daymark, underneath the horizon at night.

In the summer, when the Sun is up almost all of the time, the Sun appears to travel around the circle in a clockwise fashion. Even at midnight, there may be enough twilight lingering in the north to show where on the horizon the Sun would be. If the farm were far enough north, the Sun might even be visible above the horizon at midnight during the middle of the summer.

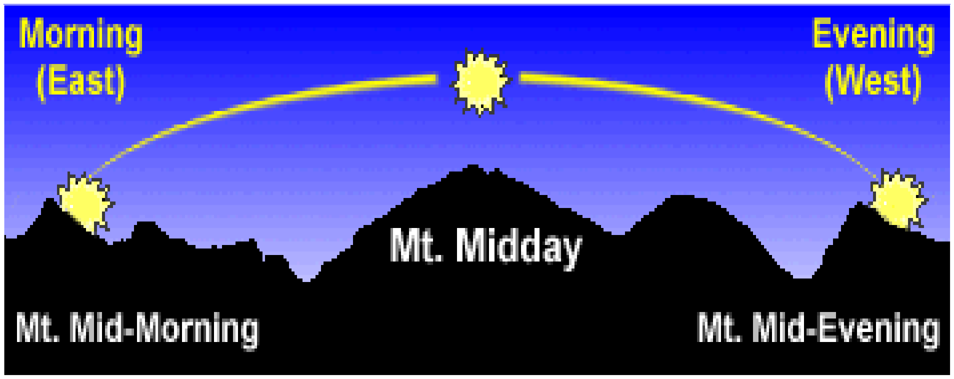
In our modern system of telling time, if the time is halfway between one hour and the next—between 2 p.m. and 3 p.m. for example--we might say it was "half past two". The Scandinavians used a similar system when the Sun stood halfway between two daymarks. In such a case, they would say it was "evenly near both" (*jafn nærri bá_u*) daymarks. So if the Sun were between the Midday and Undorn daymarks, they would say, "It's evenly near both Midday and Undorn."

Daymarks on the Horizon



This diagram shows a view south from the same Scandinavian farm, with mountains on the horizon drawn in black. It shows how the daymarks work, using the Midday daymark as an example. The people living on this farm could watch the Sun's path everyday and find where its highest point was--and in this diagram the Sun is shown at the highest point in its path. What did the Scandinavians call this place in the Sun's path? They called it **Midday's Place** (*hádegista_* or *middagsstad*).

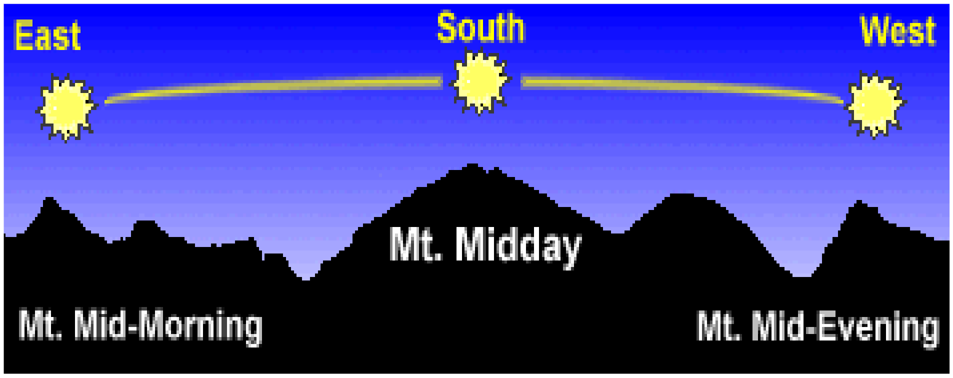
Conveniently for the people on this farm, there is a large mountain directly beneath Midday's Place which they can use as a daymark. Which daymark is it? It is the **Midday** daymark. They might name the mountain under the Midday daymark something like "**Mount Midday**". Then they will know that whenever the see the Sun over Mt. Midday, that the time is "Midday".



Above is a diagram showing a view from the same imaginary Scandinavian farm. This view shows the Sun's path on the equinoxes, either autumn or spring. The Sun is shown its positions at **Rise-Measure's Place** (sunrise), **Midday's Place**, and **Mid-Evening's Place** (sunset). The Sun's path is drawn in yellow.

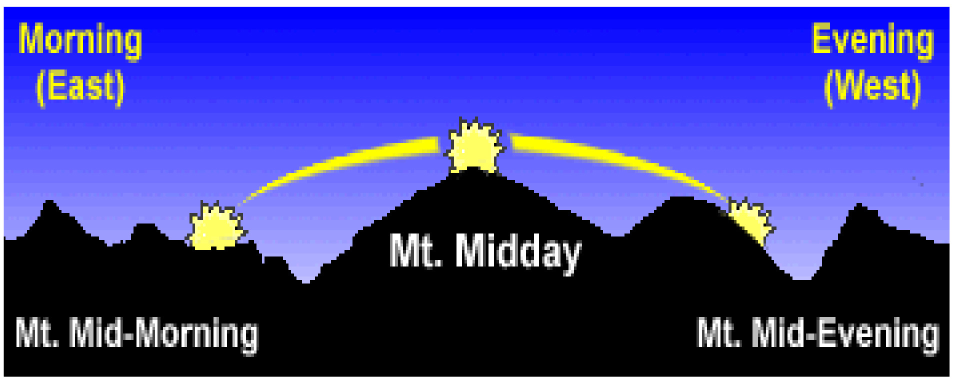
The mountain which marks the Midday daymark is named Mt. Midday. On some farms, the people might find mountains for the other daymarks and name them, too—or they might use other features, like passes, waterfalls, etc. In this diagram, there are mountains named after the Rise-Measure and Mid-Evening daymarks, and their names are in brackets.

Summer and Winter and the Daymarks



Now look at the view from the same farm in summer. Where is the Sun's path now? The Sun is very high in the sky, even when it is over the Rising-Measure and Mid-Evening daymarks! During the summer the Sun's path is longer than it is at the equinoxes and much, much longer than it is during the winter. But no matter how high or low the Sun is in the sky, it still arrives over the daymarks at the same time. This means when the Sun is at its highest point in the winter it is still over the same daymark as in the summer. So when the Sun is over Mt. Midday it means that the time is Midday, whether it is winter or summer. It's highest point during the winter is not as high as its highest point during the summer.

During the summer in Scandinavia, the Sun scarcely ever sets—particularly in the northernmost sections. The diagram above shows what a view north from the same Scandinavian farm might look like at Midnight in the middle of the summer. The twilight glow of the Sun is still visible, even though the Sun is below the horizon. This is the lowest part of the Sun's path. At the Midnight daymark on the northern horizon there is a pass—a gap in the mountains—which the people living on the farm might name after the daymark. Perhaps they might call it Midnight Pass, just like they called the mountain to their south Mt. Midday, after the Midday daymark.



Here is a diagram showing a view from the same imaginary Scandinavian farm, except that this view show's the Sun's path during the winter. What is different about the Sun's path now? It is shorter. The Sun rises and sets closer to the middle of its path than it does in the equinoctal diagram above. The Sun is also lower in the sky. But is the Midday Place in the winter still the same as the summer Midday Place? It is. No matter what time of year it is, the Sun is always highest in the sky over the same spot on the horizon (due south).

Is this also true for the other daymarks? It is. Even if the people on the farm cannot see the Sun because it is below the horizon, the daymarks remain at the same place (and same time). However there is a problem! If during the winter the Sun is only above the horizon around Midday, then no one can tell what daymark it is at. This seems like a big problem. However, during the winter it was so dark and cold outside that people spent most of the time indoors, resting, entertaining themselves, or doing indoor tasks. In such cases it wasn't so important to know what time it was.

On the other hand, in the summer, there was a lot of activity—and luckily the Sun would be up most of the time, so that it would be very easy to tell what time it was.

However, if any daymark would be visible in winter, it would be the Midday daymark. Why is this? It is because Midday occurs when the Sun is at the highest point in its path. Perhaps this is why there are more mountains named after Midday than any other daymark.

Daymarks and Day Sections Among Other Peoples

The Scandinavians were not the only people to use the surroundings to help them tell the time. In the area around Antananarivo in Madagascar people where the Sun stood in the sky in relation to different parts of their houses. For example, when the Sun was over the ridge of the roof, it was midday. They could do this because they always built their houses in the same way, with the length running north and south.

Many, many peoples around the world divided their day up into sections which, like the Scandinavian daymarks, would change in length at different times of the year. This is because these people, like the Scandinavians, were farmers who were more interested in using the sunlight than having hours of the same length like we are! The Native American Natchez people of Louisiana, USA divided up the day-light time into four sections, just like the Scandinavians. Many other Native American tribes did the same.

Class Projects

Schoolyard Daymarks

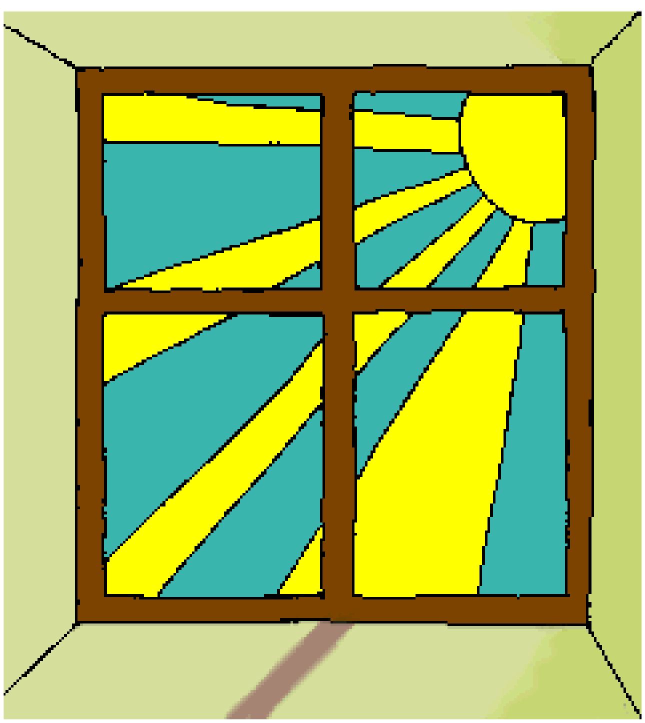
You might try having the class calculate measurements of "temporal hours" for their hometown. Depending on the time of the year, it might be possible for them to observe sunrise or sunset directly, either at school or at home. If they cannot record these measurements directly, one possibility would be providing them with a set of sunrise and sunset times over the year and having them make the calculations (if their math skills have reached this level) of dividing daytime and nighttime into 12 sections each. This, however, would not provide the students with the experience of direct observation that is at the heart of the Threads of Inquiry. Instead, you could choose other ways of splitting up the day. Suppose they divided the amount of time they were at school into twelve "school hours" and the time they were at home into twelve "home hours". The "school hours" would be much shorter than the "home hours". What would happen in the summer? There would be no "school hours" at all! Perhaps this system would not work so well over the whole year.

You might also have the students experiment with a daymark-system. They don't need to live on Scandinavian farms, they can try them out at their own houses or at school.

First they will need to observe the path of the Sun to find the highest point in the Sun's path. Go outside in the hours around 12 noon for several days to find this time. During *Hello, Sun!* (and later more mathematically in *This is a Stickup!*), the class found out how to record the Sun's path and to find out when it was highest in the sky. All they need do now is find what is on the horizon beneath the Sun when it is in Midday Place at its highest point. There need not be a mountain there—a building, a tree, anything to mark the spot will do. When the ancient Scandinavians didn't have a natural feature to mark the spot for them they would often build a little pile of stones out towards their horizon. Perhaps you can mark the spot with a pole or with colored ribbons. If nothing else, you might have the students draw a large panoramic view of the horizon and draw the Sun's positions on it, marking the Midday daymark.

If you can, have the students note the positions of the Sun at the beginning and end of the school day (probably easier than sunrise and sunset!) at different times during the school year. Perhaps you can find or make various daymarks for the other "eighths". You can even have them invent names for times of day which are meaningful to them: School-Start for the morning and Go-Home for the afternoon, perhaps. Have them see how the daymarks for these times can change over the year, while the Midday daymark stays steady. The same experiments can be done at the students' own homes as well.

Class Noon-Line Project



Another project could be making a window **Noon Line**. This was a device used by farmers in Skåne, Sweden to mark Midday. Find a south-facing window which has several panes of glass. Notice how the solid framework between the panes casts shadows onto the window sill. When the Sun is at its highest point (at Midday) you can mark the line of the shadow cast by the pane frame with masking tape. This effectively turns the window into a simple sundial. Whenever the shadow of the pane frame matches the line of tape, that means it is Midday.

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Stonehenge and Timekeeping

Something we have not talked about much in the Threads is the fact that the position of the sunrise on the horizon changes during the year. This is because of the tilt of the Earth. In the Summer months, the Sun scoops out a larger arc on the sky, rising and setting further in the North (in the Northern Hemisphere) than it does in Winter.

The Neolithic cultures of the British Isles were aware of the changing sunrise positions throughout the year. From as long ago as 3100 B.C., these people were using their experiences about the Sun to tell time. Before they learned to farm and keep cattle, they were nomads, following herds and gathering whatever grains and vegetables they could find. With farming came the responsibility of knowing when to plant and harvest. It became necessary to keep a rough calendar that everyone could use easily and quickly to find out when to plant their crops.

The Neolithic people in the British Isles constructed enormous monuments across Ireland, Scotland and England. The monuments vary in size and roughly in shape, but many incorporate a solar time keeping device in their design. One of the best examples is Stonehenge, near Salisbury in England, which incorporates a certain special date into its design. How was it done? The idea is that you stand in one place and watch the sunrise from that place on the special day. You place a big station stone in a deep hole where you are standing. As the Sun is rising, you call to someone to place a stone a little further away from where you are standing but along your line of sight of sunrise. The two stones will always line up with the sunrise only on that special day.

If you look at a photograph of Stonehenge, you will see there are far more than just two simple stones in the monument. Some say that the circle design was for festivals or meetings. Others say that stones on one side of the circle can be used to line up with others across the circle to mark celestial events on the horizon.

Although there are many theories and ideas about why Stonehenge was built, we do know that the people who built it did indeed keep track of one special date: The Summer Solstice! What happens to the sunrise position on this date? It is farthest to the north. The Neolithic farmers would watch the sunrise from the station stone every so often to see how close the sunrise was getting to the line. They would have other clues about the time of year, right? So, they wouldn't have to check every single day!

Imagine now that you are a farmer from thousands of years ago. You are trying to set-up a device to keep track of time, and you have figured out the Sun changes its rising position in a year. With what would you build your device? What shape would you choose? How big would you make it?

Pick a special date to make your device/monument. What does your idea look like on paper? Can you build a model out of clay? Where is North? Where is the Sun going to rise? Where do you have to stand to wait for the special date.

Word Lore

Origins of
Vocabulary Words
from the Threads of
Inquiry

This is a document designed to explore certain words we use a lot in the Threads of Inquiry. Here we learn about how ancient and modern cultures use the following words and from where the origin of the word has come. Since it is always a difficult decision whether or not to introduce new vocabulary words to students when they are trying to experience concepts without them, this page may offer a teacher an interesting approach to presenting certain words to the class. A brief note: This document assumes students are from the United States, however, the information gathered here can be adapted for any country.

Words we examine:
Sun • Shade & Shadow • World • Earth • Light • Dark • Day • Night • Time • Spring • Fall • Summer • Winter

About Our Language

What language are we speaking? It is *English*. Why is it called that? It is the language which is spoken by English people who live in England. Even though we are not English, our language is still called English because it is very similar to the lanaguage that English people speak in England.

In fact, American English is slightly different from British English. Hundreds of years ago, the first English speaking people came to America from England. Since that time, the English language has been spoken both in America and in England, but it has changed just a little bit—and in different ways—in both countries. Now there is enough of a difference between the languages spoken in America and England that sometimes people call the English spoken in America *American English* and the English spoken in England *British English*.

Over long periods of time, the language a people speaks changes very slowly. Usually, these changes take place so gradually that the people speaking the language probably won't notice the changes. But after hundreds of years, the changes become apparent—just has they have with British English and American English. Eventually a language can change so much that it can't really be called the same language anymore. Perhaps one day American English will be so different from British English that we won't call the language spoken in America "English" anymore.

Even before there was a special kind of English spoken in America, the English language in England had been slowly changing for a very long time indeed—over a thousand years! If we had a time machine that would allow us to meet and talk with people who lived in England six hundred (600) years ago, we might have a lot of trouble understanding them. Today we call their kind of English *Middle English*. If we used our time machine and went back to talk to people who spoke English one thousand (1000) years ago years ago, their English would be so much different from ours that we could hardly understand them at all. We call their kind of English *Old English*. Before that time, the language was so different that we don't even call it English.

Any language can change so much that it needs a new name. Sometimes a language will change differently in different places, and it will need two or more new names. It is possible to draw a picture like a family tree showing how languages change. About two thousand (2000) years ago there was a language we call *Germanic* (or *Proto-Germanic*). It was spoken a little differently in different places, and slowly turned into a number of different languages, including English. Just as English is descended from Germanic, Germanic is descended from another language we call *Indo-European* (or *Proto-Indo European*). Indo-European was spoken perhaps six thousand (6000) years ago. At the end of this document is a language family tree showing how Germanic and English evolved from Indo-European.

We can learn many different things by looking at how a language changes. Below are a number of terms and vocabulary words taken from the Threads of Inquiry, each of which has a brief discussion about its history and the folklore associated with it. By introducing such concepts, we find that the subjects we investigate are all interconnected.

Brief Pronunciation Notes

For the purposes of comparing similar words in different languages, spelling is often enough. However, the students may have fun learning how to pronounce some of these words—doing so also gives additional insights on how languages change, since spelling does not always reflect pronunciation (especially in English!). There are samples of so many different languages on this page that it would be difficult to provide information on how to pronounce them all (and, in fact, the authors have very little idea about how to pronounce some of them!). However, it is possible to briefly note a few important points without undue oversimplification.

Unlike modern English, most languages (including Old and Middle English) have few or no “silent letters”. Thus the Norwegian word *time* is not pronounced at all like the English word “time”—the Norwegian word is pronounced something like “TEEM-eh”.

The letter **i** is usually pronounced “ih”, although in the North Germanic languages **í** and **i** are often pronoucned “ee”. In general, **e** is pronounced “eh” in most of the sample languages, and **a** is pronounced generally closer to as in English “f**a**ther” while **o** is pronounced generally closer to as in English “b**o**x”—though “long o” (**ó** or **ô**) is pronounced as in English “n**o**te”. On the other hand, “o umlaut” (**ö**) and “slashed o” (**ø**) are pronounced like the “ea” sound in English “**ea**rn”. The letter **y** is often pronounced with one's mouth in position to say “oo” (as in “b**oo**t”), but then trying to make an “ee” sound without changing the position of one's lips (similar to German “**ü**”).

Some letters or letter combinations have special sounds. The “ch” sound as in Scottish “lo**ch**” or the name of the composer “Ba**ch**” is represented by the following letter combinations:

- Old English/Gothic: **h**
- Middle English: **gh**
- Frisian/German/Dutch/Afrikaans: **ch**

Thus Old English “liht”, Middle English “light”, and High German “Licht” are all pronounced in very much the same way (“lih**ch**t”).

In Old English, **sc** was pronounced like modern English “sh”—Dutch and German **sch** are pronounced the same way. In every Germanic language except English, **j** is pronounced like the consonant “y” in “**y**ellow” “(except in Dutch **ij**, which sounds like “ee”). In High German, **s** is pronounced like English “z”, and **w** like English “v”, while High German **ei** sounds like the English word “eye”. Italian **ce** and Spanish **che** sound something like “chay”.

Selected Words from the Threads of Inquiry

SUN

“Sun” is a very old word. This is because people have always needed a word to describe that big, fiery thing that appears to move across the sky.

People who spoke Indo-European six thousand (6000) years ago might have used a couple of different words for “Sun”. Even then, language had changed enough in different places where Indo-European was spoken that we can't find just one word for “Sun”! Some people might have said something like *suen*, while other people said something like *sáwel*. Both these words start with similar sounds (*su-*/*saw-*), but have very different endings (*-n* or *-l*).

Both these words for sun were still used in Germanic, about two thousand years ago. People who spoke Germanic might have said something like *sunnón* or *suól*. English (and other West Germanic languages) are descended from the language used by Germanic-speaking people who said *sunnón*. One thousand (1000) years ago, the people who spoke Old English said *sunne*. Other Germanic languages descended from those used by Germanic speakers who said *sunnón* (mostly West Germanic languages) have words for “Sun” which look a lot like the English word “Sun”:

- West Frisian: sinne
- Dutch: zon
- Afrikaans: son

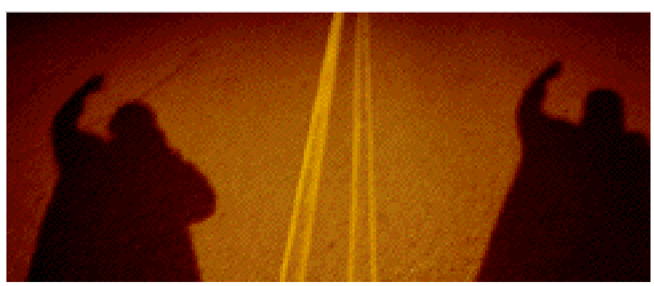
- Low German: sunne
- High German: Sonne
- Gothic: sunnô

Languages descended from those used by Indo-European speakers who said *sáwel* (and from Germanic speakers who said *suól* (mostly North Germanic languages) have words for "Sun" which look like these:

- Gothic: sauil
- Icelandic: sól
- Danish: sol
- Norwegian: sol
- Swedish: sol
- Latin: sol
- Spanish: sol
- Portugese: sol
- Italian: sole
- French: soleil
- Occitan: solèlh

Today we usually think of the sun as an "it". Sometimes people might refer to the sun as if it were a person, and often they will speak of it as if it were male (as in, "The sun is shining, and his rays are very warm."). However, English-speaking people thought of the Sun as "she" for a very long time—up until the 1500s, about five hundred (500)years ago.

SHADE and SHADOW



Look at the words "shade" and "shadow". What do you notice about them? One thing students might notice is that they start with the same letters: shad-. They might also notice they have similar meanings: casting a shadow makes shade. If they think these words are related, they are right!

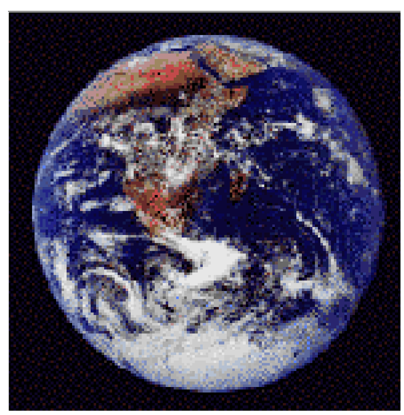
A thousand (1000) years ago, people who spoke Old English said *sceadu*. This word basically meant "shade". Six hundred (600) years ago the people who spoke Middle English used the word *schade* which eventually turned into our word "shade".

There were other forms of Old English *sceadu*, though, including the oblique case form *sceadwe*.[1] This eventually turned into our word "shadow". Since both "shade" and "shadow" come from one word (Old English *sceadu*), their meanings are very, very similar. In fact, you can try making sentences using only one of the words, and then try substituting in the other to see if the sentence still makes sense. Most of the time it will make sense, although it might sometimes sound a little funny. People tend to use "shade" and "shadow" slightly differently even though they mean almost the same thing. See if the students can figure out how they use both words.

About two thousand (2000) years ago, people who spoke Germanic might have said *ska_woz* or *skadwaz* to mean "shade" (or "shadow").[1] About six thousand (6000) years ago people who spoke Indo-European might have said *skotwós* or *skotos*. This turned into words with related meanings in different later languages; the Greek word for "darkness" is very similar: *skotos*. Here are words meaning "shade" or "shadow" in other Germanic languages—most only have one word for "shade" and "shadow":

- West Frisian: skaed
- Dutch: schaduw
- Afrikaans: skadu
- Low German: schadde
- High German: Schatten
- Gothic: shadus
- Irish: scáth
- Breton: scod
- Cornish: scod
- Welsh: cy-sgod

WORLD



What in the world does the word "world" mean? In these Threads we mostly use it to refer to the planet Earth, which we live on. But sometimes we can use the word world with slightly different meanings. We might use it to refer not only to the planet Earth, but to include the people who live on it, or the plants and animals who live on it, or even inanimate things like lakes, rivers, and oceans. The word "world" exists only in the Germanic languages. The reason for this is that is actually the combination of two words. The first part of the word is *wer-*, from Germanic *weraz* or *wiraz* which means "man"—this same element gives us the "were-" in "werewolf", which means

1. The *oblique case* will be described by most basic books on linguistics or grammar. Concepts like grammatical case might be a bit beyond many elementary school students, unless they are already learning a language that still uses cases like Latin or German. In short suffice it to say that in Old English, people used different forms of a word depending on where they appeared in the sentence, and as time went on and the language became simpler these different forms sometimes became confused.
1. The character *†* is pronounced like the "th" in words such as "this" or "bathe". It was originally invented by Anglo-Saxon scribes for writing Old English, but eventually fell out of use in English writing.

"man-wolf". The second part of the word was from *alda*, which means "old" or "age". So, when put together in Germanic, as it might have been used two thousand (2000) years ago, *werald* means "the age (or life) or man". Eventually the word came to mean "things that have to do with humanity" and the original meaning began to become less important. Later, it eventually came to refer to the planet Earth and everything in it. People who spoke Old English one thousand (1000) years ago might have said *weorold* or *worold*. Here is how the old Germanic word *werald* turned out in other Germanic languages:

- East Frisian: warld
- Dutch: wereld
- Afrikaans: wêreld
- Low German: werld
- High German: Welt
- Icelandic: veröld
- Swedish: verld
- Danish: verden
- Norwegian: verden

There are many words in modern English that are made up of combinations of two other words, just like "world" (*weraz* + *alda*) and "werewolf" (were [man] + wolf) are. Perhaps the students can think of some of these. Far in the future, maybe some of the compound words will have merged so fully (like "world") that it will be difficult to see what two words the originally came from. Perhaps the students can make guesses about how some of these words might one day look like. Maybe some of these words will also change somewhat in meaning (like "world" did). What might their new, but related, meanings be?

EARTH

Where on earth does the word "earth" come from? "Earth" is another word which is found almost exclusively in the Germanic languages. Probably people speaking Germanic about two thousand (2000) years ago said something like *er†ó* or *er†â*.[1] This word already meant "earth" even then, and no one has any certain ideas what the word might have been like earlier or what it meant. About one thousand (1000) years ago people speaking Old English might have said *eor†e*.

1. The character † is pronounced like the "th" in words such as "**Th**ursday" or "**th**ink". It was originally borrowed from the Germanic runic characters by Anglo-Saxon scribes for writing Old English, but eventually fell out of use in English writing. Though few realize it, the letter † survives as *y* in phrases like "**Y**e Old Toy Shop". During the period when Middle English was written, the way in which people wrote † slowly changed to look similar to the way in which they wrote *y*. Eventually, the distinction was forgotten!

The word "earth" can be used to mean a number of different things. It can simply mean "dirt". This may have been one of the earliest meanings. What do we stand on? If you are inside you are probably standing on a floor, but if you are standing outside you are often standing on dirt. Perhaps, people came to think of the whole area they were standing on as "dirt" or "earth". By the time people were speaking Old English, about one thousand (1000) years ago, *eor_e* could already mean the world on which people live. It took longer for "earth" to come to mean "Planet Earth"—until around 1400 CE, or so. Here is how the old Germanic word *er ó* turned out in other Germanic languages:

- Frisian: ierde
- Dutch: aarde
- Afrikaans: aarde
- High German: Erde
- Gothic: aír a
- Icelandic: jör_
- Swedish: jord
- Danish: jord
- Norwegian: jord

LIGHT

"Light" is another word common to all the Germanic languages. About six thousand years (6000) ago, people who spoke Indo-European all used words having to do with shining or being white-colored that began with the sound *leuk-*, although in different areas they may have used different endings for the word—already at that time the word was changing! People speaking Germanic about two thousand (2000) years ago probably said something either like *leuktom* or *leuksa* which meant "light". People speaking West Germanic used *leuktom*, and by about one thousand (1000) years ago, people speaking Old English had changed this word to *léoht*. This word slowly changed to *leht*, then *liht*, and finally to Middle English "light", which was spelled the same way as our word "light". Here is how *leuktom* turned out in other West Germanic languages:

- Frisian: ljocht
- Dutch: licht
- Afrikaans: lig
- Low German: licht
- High German: Licht

Here is how *leuksa* turned out in the North Germanic languages:

- Icelandic: ljós
- Swedish: ljus
- Danish: lys

Here is how the Indo-European basic sound *leuk-* turned out in other non-Germanic languages:

- Latin: lux
- Spanish: luz
- Portugese: luz
- Italian: luce
- Occitan: lutz

DARK

"Dark" is a strange and rare word for such a common concept. Everyone needs a word to describe the abscence of light, but there are a number of different words in the Indo-European languages to describe this concept! Sometimes people make special words to describe concepts which are frightening or disturbing. Perhaps some students will admit to being afraid of the dark—such feelings may have been quite common long ago, before electric lighting allowed us to reduce the amount of dark so easily.[1]

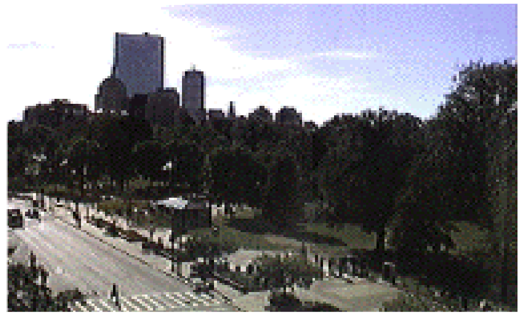
In any case, about five hundred (500) years ago people who spoke Middle English said *derk*, which was changed from the word *deorc* used by speakers of Old English about one thousand (1000) years ago.

No one knows exactly where the Old English word *deorc* came from. There is a similar word found only in *Old High German* (which was spoken in southern Germany about one thousand years ago) *tarchanjan*, meaning "to hide" or "to conceal". You can see how the start of this word, *tarch-*, is similar to "dark". Perhaps speakers of Old English described the absence of light as that which hid things or concealed them. It is possible that both *tarchanjan* and our word "dark" come from a West Germanic word like *darknjan* which was used two thousand (2000) years ago.

1.Sometimes something is considered so special—either frightening, or holy, or powerful, etc.—that people are uncomfortable talking directly about it. Often they will make a new word to describe it, and not use the old one anymore. In such cases, the old, uncomfortable word is known as a "taboo word". Something is "taboo" if people are uncomfortable referring directly to it. Many words which we now consider common began as replacements for taboo words describing special things. The word "bear", for example, is related to the Indo-European word for "brown", rather than the original Indo-European word for "bear" (*rtko-*, which survives in southern European words, like Latin *ursus*). Bears were considered very special and powerful creatures and it is thought that in the northern European languages, people made a new word for them because the original word was too powerful to be used regularly.

It is not sure whether "dark" is such a word, but it might be. It makes a good introduction to talking about what people consider powerful or frightening and how they deal with it. Such concepts are often central to a culture's folklore.

DAY



How do we know when it is day? When the Sun is visible in the sky. This explains the origin of our word day, which seems to have come from an Indo-European form *dhegh*- or *dhegwh* which had to do with heat, burning, and times when it was warm. For example, the Sanskrit word *dah* means “to burn” and Albanian *djek* means “burnt, while Lithuanian *dagas* means “hot season”.

About two thousand years (2000) ago, people speaking Germanic said *dagoz*, meaning “day”. People speaking Old English about one thousand (1000) years ago said *dæg*. There were many different forms of this word used by speakers of Middle English about six hundred (600) years ago, including *dag*, *daw*, *daig*, and *dai*. Eventually these were simplified into our word “day”. Here is how the Germanic word *dagoz* turned out in other Germanic languages:

- Frisian: dei
- Dutch: dag
- Afrikaans: dag
- Low German: dag
- High German: Tag
- Gothic: dags
- Icelandic: dagur
- Swedish: dag
- Danish: dag
- Norwegian: dag

Some other Indo-European languages have a word for “day” which sounds similar to our English word “day”. Actually, these other words are unrelated to English “day”, and the similarity is merely a coincidence.

- Latin: dies
- Spanish: día
- Portuese: dia

NIGHT

Compared with the word “dark”, the word “night” is a surprisingly common one. Words very much like “night” appear in many Indo-European languages. Six thousand years ago, people who spoke Indo-European may have used a word like *nokt*. By the time people were speaking Old English one thousand years ago, this word had only changed a little, to *neaht* or *niht*. People speaking Middle English about six hundred (600) years ago had changed the word to *nyght*, which is very similar to our word “night”. Here is how the Indo-European *nokt* turned out in various Germanic and non-Germanic Indo-European languages:

- Frisian: nacht
- Dutch: nacht
- Afrikaans: nacht
- High German: Nacht
- Gothic: nahts
- Icelandic: nótt
- Swedish: natt
- Danish: nat
- Norwegian: natt/nott
- Latin: nox
- Spanish: noche
- Portugese: noite
- Italian: notte
- French: nuit
- Occitan: nu_ch
- Russian: noch’

TIME (& TIDE)

What is time? It's a thing which is so basic to our existance, that it is very hard to describe well! We all know time as the thing which a clock measures the passing of, but what it is, really? Perhaps the simplest way of describing time is to call it the system of sequential relations between events. We might also call time a period of continued existence.

Meanings like these have to do with dividing up a sequence of events into sections. Not surprisingly our word for “time” goes back to an ancient Indo-European form used about six thousand (6000) years ago: *dai-*. By the time people were speaking Germanic, about two thousand years ago, *dai-* was being used in two Germanic words: *tídiz* (meaning “a division of time”, and *tímon* (meaning something like “an appropriate time [at which to do something]”).

The *tídiz* word became Old English *tíd* and our word “tide”. In our modern English we usually use “tide” to mean the way the ocean rises and falls over periods of time (as in “high tide” and “low tide”). See how this meaning is linked to the concept of time? One thousand (1000) years ago, Old English had no one word for the ocean's tide—instead people referred to *flód* (flood or high tide) and *ebba* (ebb or low tide). A few centuries later, during the time people in England were speaking Middle

English, northern Germany (where people then spoke *Middle Low German*) was an important center for sailors, shipping, and nautical technology. There was a Middle Low German word *getîde* which had acquired meanings which originally belonged to the ancient Germanic word *tímon*: “fixed time, proper time, opportunity”. Middle Low German *getîde* also came to refer to times of the ocean's tides (which happened at fixed times, and were opportunities to use their power to help move a ship). This new meaning was borrowed for the regular Middle English word *tide* (meaning “time”) in the early 1300s, when *tide* in English could refer to the “time” at which the ocean's tides took place. Within the next hundred years, by the 1430s, the English word *tide* had come to mean the tidal motions of the ocean themselves, rather than merely the times associated with these tidal motions. Middle Low German *getîde* led to modern Low German *tîde* and Dutch *tij*, both referring to the ocean's tides.

The word “tide” however, did not entirely lose all its old associations with time, even after receiving this new meaning. Even now, some old-fashioned expressions use “tide” to mean “time”, like “Yule**tide**” or “even**tide**”. “Tide” also survives in the slightly archaic word “tidings” (as in “glad **tidings** we bring”) which means “news” (in the sense of “timely information”). This modern English word “tiding” (Middle English *tídung*) seems to have been borrowed almost a thousand (1000) years ago from the Old Norse word *tí_endi*, which meant “events”. This word *tí∂endi*, comes originally from the ancient Germanic *tídiz* word. It is interesting to note that words related to “tiding” appear in other Germanic languages with similar meanings, such as Swedish *tidning* and High German *Zeitung*, both meaning “newspaper”.

Most other Germanic languages use a word that changed from *tídiz* to mean “time”:

- West Frisian: tiid
- Dutch: tijd
- Afrikaans: tyd
- Low German: tid
- High German: Zeit
- Icelandic: tí∂
- Swedish: tid
- Danish: tid
- Norwegian: tid

By the time people were speaking Old English, about one thousand (1000) years ago, the old Germanic word *tímon* had changed to *tíma*, which could mean “time” or “opportunity”. About six hundred (600) years ago, when people were speaking Middle English, this word had changed to *tyme*, which is very similar to our spelling of “time”.

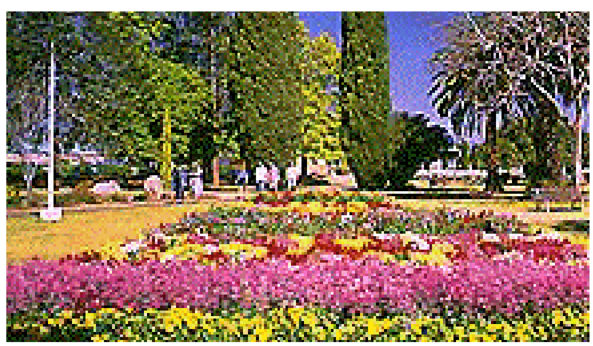
The North Germanic languages do have a word that changed from *tímon*, as did our word “time”. They, however, do not mean “time”, but have a meaning that is related to the concept of time:

- Icelandic: tími (meaning “hour”, OR
  “appropriate time”, “lucky time” or “prosperity”)
- Swedish: timme (meaning “hour”)
- Danish: time (meaning “hour”)
- Norwegian: time (meaning “hour”)

All the North Germanic languages have changed the meaning of their word descended from Germanic *tímon* to “hour”—only in Icelandic preserves a alternate meaning very similar to the original meaning of Germanic *tímon*.[1] Why? Originally, the Scandinavians (who are the people who speak the North Germanic languages) had their own system of measuring time. They did not use hours, but instead used three-hour divisions of time called *eyktar* or *ættir*. After the Scandinavians were converted to Christianity, the Roman system of time-keeping, as used by the Christian Church, was introduced to their culture. The Roman system, which used 24-hour days, is the basis of our modern system of time-keeping. The Scandinavians needed a new word for the concept of an “hour”, and instead of borrowing the Latin word (as English did: Latin *hora*, through Old French *oure*) they altered their word which meant “appropriate time” to mean “hour” (in the sense that when it is a certain hour, that is an appropriate time for a given event). The Roman/Church method of time-keeping, however, was the high-class, learned method, and as is often the case in such situations, the older native method of time-keeping persisted side-by-side with the Roman/Church method in rural areas of Scandinavia for centuries.

On the other hand, English speakers expanded the meaning of their word *tíma* into a general word for time. It's older sense of “appropriate time” only survives in expressions like “It is **time** to go,” or “It is **time** for lunch” (meaning that it is the appropriate time to go or to have lunch). When people were speaking Middle English, about six hundred (600) years ago, they sometimes used “time” to mean “hour” (as Swedish/Danish/Norwegian do) but “time” could also sometimes mean “year”.[2]

SPRING



What do we call the season that follows Winter? It is Spring. Why do we call this season “Spring”. Can the word “spring” have other meanings? What other meanings can the word “spring” have? It can mean “to jump” or “to leap”. It can mean “a place where water comes up out of the ground” (in other words, the water jumps—or springs—out of the ground). It can mean “a bouncy piece of coiled

1. Although Icelandic *tími* can be used to mean “hour”, the word *stund* or *klukkustund* is also common. *Klukka* means “bell”, and is related to the English word “clock”.
2. The use of the word “time” to mean “year” was the result of overly literal biblical translations. It was, however, used in this fashion on occasion into the early 1800s

metal" (in other words, the because of its shape and elasticity, the metal can jump—or spring—back into shape after pressure has been applied to it).

All these meanings have to do with jumping, or vigorous sudden activity of some kind. Can you guess what the season following Winter is named? It is Spring. What kind of things happen in Spring? What happens in nature? Plants begin growing quickly once the cold of winter has ended. One might say the new growing is practically *springing* up. And that is why we call this season Spring!

"Spring" is an old word, and appears in many Germanic languages with a meaning like "to jump" or "to run". About two thousand (2000) years ago, the basic Germanic form was *spreng-* and by about one thousand (1000) years ago, when Old English was spoken, the word had changed to *spryng* or *spring* and has not changed significantly since then! However, the word "spring" was only began to be used to name the season following Winter in the 1500s (about five hundred (500) years ago). People had been using expressions like "spring of the leaf" and "spring time of the year" to describe the new growth of this season, and it seems likely that the season name "Spring" was formed from such expressions.

So what did people call this season before they called it "Spring"? In fact, the common Old English word naming the season following winter was *lencten*, *lengten* or *lenten*. This word is related to our word "long", perhaps coming from a Germanic form something like *langiton* used about two thousand (2000) years ago. Possibly, the word was used for the season following Winter because this was the time when the Sun's path was noticeably higher in the sky and the time of daylight lengthened—you can see how similar the modern English word "lengthen" is to the Old English word *lengten*! This word survives in our Modern English "Lenten" or "Lent". This word is now most commonly associated with the Christian Lent holidays which take place in late Winter or early Spring. Lenten originally was just the season name, however, and only began acquiring its Christian associations after the Anglo-Saxons (which is the name we give to the Germanic inhabitants of England who spoke Old English between about 600 and 1100 CE) were converted to Christianity. In fact, the earliest use of it in a Christian context is from around 1020 CE.

English is the only Germanic language in which a word related to "Lenten" has a Christian religious association. It was used as a common name for the Spring season which followed Winter in several other West Germanic languages: Middle Dutch *lentin* and Old High German *lengizin*/*lenzin*. Middle Low German and Modern Dutch *lente* are closely related forms also.

However, the various modern Germanic languages use a wide variety of words for the season "Spring", many of which are related neither to "Spring" nor "Lenten"—for example, modern High German *Frühling* and Swedish *vår*. This much variation in names for the same season is very surprising when compared to words for Summer or Winter, most of which are nearly the same in the Germanic languages. This suggests that the season we call Spring may not have been as important as Summer or Winter. In fact, some old Germanic cultures only counted two seasons in the year—Summer and Winter—and didn't count Spring or Fall at all.

AUTUMN & FALL

What do we call the season which follows Summer? It can have two names: “Autumn” or “Fall”. Which one do the students use most often? Nowadays, the name “Fall” is probably used most often in American English, though “Autumn” is used as well. In British English, however, the word “Autumn” is used almost exclusively—British English used the word “Fall” for this season quite often, though now it is only sometimes found in some dialects of British English.

Why do you think this season might be called “Fall”. What happens in the natural world during this season? The leaves on many trees die and *fall* to the ground. About five hundred (500) years ago, when Middle English was spoken, expressions like “fall of the leaf” and “fall of the year” were quite common, and the season name “Fall” comes from them. It is interesting to note that although Old English, spoken about one thousand (1000) years ago, had a word *fiæll* (or *fyll*)—meaning “fall” as in “a falling from a height”—this word not only did not mean “the season following Summer”, but did not even change into our modern English word “fall”! Instead our word comes from the Old Norse word *fall* which, like Old English *fyll*, also meant “a falling from a height”. However, during the period after the Scandinavians (who spoke *Old Norse*) settled in England (between 800 and 1100 CE) their word *fall* was borrowed into English and replaced the Old English word *fyll*. There are many other Old Norse words which were borrowed into English at this time. But the word *fall* only came to refer to the season “Fall” in the 1500s.

Before the 1500s, this season was often called “Harvest”. In fact, the name “Harvest” was used for this season quite commonly up until the end of the 1700s, after which the word “harvest” began to apply more specifically of the gathering of crops. Before the 1700s, most English-speaking people had occupations which had to do with farming, and “Harvest” was quite an appropriate name for this season when the crops were gathered in. However, after the Industrial Revolution beginning in the 1700s, fewer people were working on and around farms—in our times, most English-speaking people do not work in farming. So it is easy to see why the word “harvest” became less popular as a season name. “Harvest” comes from a Germanic word something like *harbistoz* or *harbustoz*, used about two thousand (2000) years ago—this may have come from an older Indo-European root *harb-*, used in words perhaps four thousand (4000) years ago, and meaning something to do with crops or fruit, or with plucking. By around one thousand (1000) years ago, the Germanic word *harbistoz* had turned into the Old English word *hærfest*. By the time people spoke Middle English, about five hundred (500) years ago, people were already using our word “harvest”. Here is how the Germanic word *harbistoz* turned out in other Germanic languages:

- Dutch: herfst
- Afrikaans: herfs

- High German: Herbst
- Icelandic: haust
- Swedish: höst
- Danish: høst
- Norwegian: høst/haust

The word “Autumn” is a little more mysterious. It comes ultimately from Latin *autumnus*, which itself is of uncertain origin. In Middle English, spoken about five hundred (500) years ago, it was spelled *autompne* having been borrowed from Old French *autompne* (found in modern French as *automne*. Middle English *autompne* was sometimes used to mean “Fall” as early as the 1300s, but only became common during the 1500s.

SUMMER

What is Summer? It is when school is out! It is also the warm and sunny season of the year, when sun is up more than at other times of the year and doesn't set until late in the evening. Not surprisingly, people have needed a word for summer for a very long time. In fact, of all the words for seasons used by the people who spoke Indo-European about six thousand (6000) years ago, only a descendant of one of them is still used in English: summer. The Indo-Europeans used a basic word that started *sem-*. By about two thousand (2000) years ago, people speaking Germanic had taken this basic start and turned it into *sumaraz*. People who spoke Old English about one thousand (1000) years ago said *sumor*. People who spoke Middle English about six hundred (600) years ago used a word like *sumer* or *sommer*, which has become our word “summer”. Here is how the Germanic word *sumaraz* turned out in other Germanic languages:

- West Frisian: sommer
- Dutch: zomer
- Afrikaans: somer
- Low German: sommer
- High German: Sommer
- Icelandic: sumar
- Swedish: sommar
- Danish: sommer

WINTER

What is winter? It is the cold season, the snowy season—and if it isn't quite cold enough for snow it can be the wet season as well! In fact, our word "winter" is related to our words "wet", "water", and "wash". All these words come from an Indo-European basic form *wed-*. People speaking Germanic, about two thousand (2000) years ago, used a word *wentruz* to mean "winter" (or "wet season"—for comparison, the Germanic word for "water" was *watar*). By about one thousand (1000) years ago, people speaking Old English had changed this word to *winter*—just like the modern word! Although it was sometimes spelled slightly differently (*wynter*, *wintir*, *wintur*, etc.), the word has scarcely changed at all in the past millenium. One might almost say that it had *frozen* (ha ha!).

Anyway, here is how the Germanic word *wintruz* turned out in other Germanic languages (and you can see many of them have words which are very similar to the English word "winter"!):

- Frisian: winter
- Dutch: winter
- Afrikaans: winter
- Low German: winter
- High German: Winter
- Gothic: wintrus
- Icelandic: vetur
- Swedish: vinter
- Danish: vinter
- Norwegian: vetter

However, many students may not think of winter being primarily a *wet* season. Nevertheless, in some places (both in North America and elsewhere in the world) the most noticeable thing about the winter season is that it is wet! The words people use for seasons and their folklore about those seasons can vary depending on what the local weather is like. Perhaps the students can think of other names for our seasons that describe various weather or natural events that characterize those seasons.

For Further Reading

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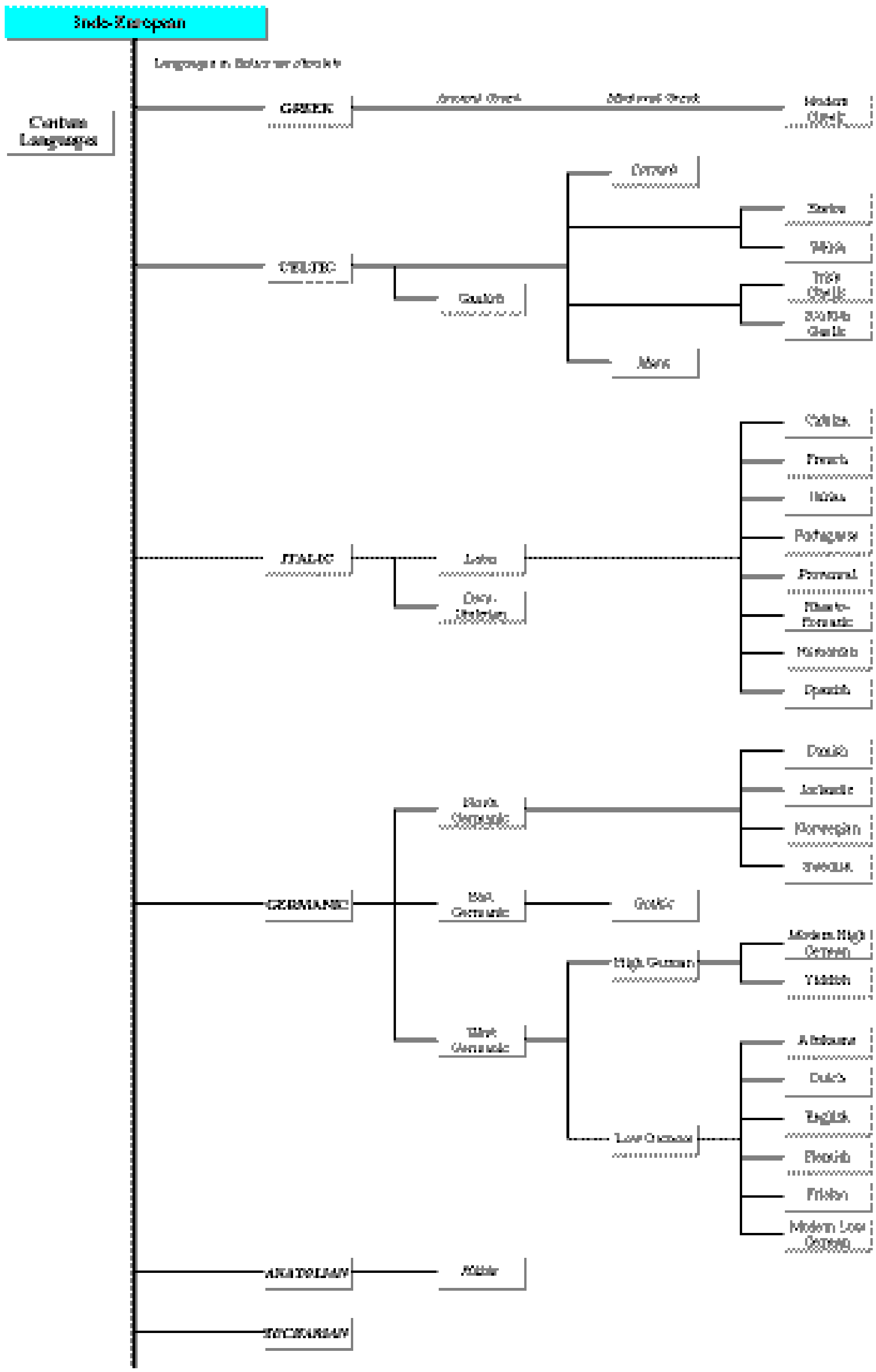
Indo-European Language Tree
Courtesy of Dan Short
http://www.georgetown.edu/cball/oe/oe-ie.html
(Note: Satem Languages have been left out.)



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Wake Up, Sun, David Lee Harrison, Random, 1986

Day the Sun Disappeared, John Hamberger. Norton, 1964

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Snow, Steve Sanfield. Philomel Books, 1995.