MESSENGER Education Module

Framing Pathways to Answers: The Scientific Process in Action

Unit 1: Staying Cool
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NASA
Challenger Center for Space Science Education is an international, not-for-profit education organization that was founded in April 1986 by the families of the astronauts tragically lost during the Challenger space shuttle mission.

Using space as a theme and the power of simulations as a teaching tool, Challenger Center programs create an exciting and cooperative learning environment that exposes students to the challenges and successes of teamwork, problem solving, communication, and decision making. These positive learning experiences raise students’ expectations of success; foster in them a long-term interest in math, science, and technology; and motivate them to pursue careers in these fields.

Our mission is to create a scientifically literate population that can thrive in a world increasingly driven by information and technology. Our vision for the future is a global community where today’s students command their own destinies by using higher order thinking skills, the lessons of teamwork, and strong communication frameworks. That vision is based on a realistic assessment of the skills needed for success in the 21st century.

Now firmly in our second decade, Challenger Center has developed into a kaleidoscope of learning innovations that serve as a gateway to knowledge. Our network of Challenger Learning Centers, and diverse classroom programming, excite students’ natural curiosities and encourage them to learn. Innovative teacher training workshops give instructors a deeper understanding of how to teach the subjects of science and mathematics, and the confidence that the programs they are using are content-rich and consistent with current scientific understanding. All Challenger Center program development and delivery teams include staff educators and space scientists to ensure accuracy in both pedagogy and content.

Challenger Center recognizes that in order to make change happen within education, we must reach all parts of the education system: students, teachers, schools, and communities. We have developed a full array of hands-on and minds-on multidisciplinary programs to accomplish this. Visit www.challenger.org for more information.

Challenger Center is the lead organization in developing the grade 5-8 and 9-12 components of this Education Unit for the MESSENGER mission to Mercury.
Carnegie Academy for Science Education (CASE)

Founded in 1902 by Andrew Carnegie as his institution for discovery, the Carnegie Institution of Washington (CIW) has been, since then, a pioneering force at the forefront of scientific research and education. Headquartered in an historic building in Washington, D.C., the Institution conducts research in five departments across the country, in the fields of plant biology, astronomy, developmental biology, and the earth and planetary sciences.

In 1988 the Carnegie Institution opened its doors to children from two neighborhood public schools and invited them to learn science at First Light, a free, all-day, inquiry-based Saturday program. Enrollment is open to all interested children attending DC Public Schools (DCPS) in grades 3 to 6 on a first-come, first-served basis. Encouraged by external advisors and DCPS elementary school principals and parents, the teaching methods developed at First Light became the basis for the Carnegie Academy for Science Education (CASE) teacher training program. Fifty teachers, primarily from schools involved with First Light, attended the first Summer Institute in 1994 where they learned science content and how to teach science and associated mathematics through inquiry based and interactive methods. Every summer since then teachers have attended the Institute, the only long-term professional development program in science and mathematics for DCPS teachers. Over 500 teachers from more than 50 schools have been trained. CASE has gained the respect of DCPS elementary teachers and principals for providing excellent professional development in science and mathematics.

CASE is the lead organization in developing the grade preK-1 and 2-4 components of this Education Unit for the MESSENGER mission to Mercury.
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Mercury is the closest planet to the Sun. Since it never strays far in the sky from the Sun’s glare, early astronomers had a difficult time viewing it, and considered it a "wandering star" appearing just before sunrise or just after sunset.

Mercury travels around the Sun faster than any other planet. During one year on Earth, Mercury makes over four orbits around the Sun. On the other hand, Mercury rotates slowly around its axis—almost 60 times more slowly than Earth. The amazing outcome is that a single day (e.g., sunrise to sunrise) on Mercury takes two of Mercury’s years.

Mercury’s orbit around the Sun is much more oval-shaped ("eccentric") than Earth’s. This means that unlike the Earth, whose distance from the Sun does not vary much during the year, Mercury’s distance from the Sun varies by about 40% during its year. As a result, the size of the Sun seen from Mercury’s surface changes by about 40%—and it is always more than twice as big as we see it from Earth!

Mercury is the second smallest planet in the Solar System, larger only than Pluto and not much bigger than our Moon. The surface of Mercury is very Moon-like, covered with ancient craters, while its interior is like Earth’s, with a large core of iron. Mercury has a thin atmosphere, and no moons of its own. It is a world of extreme temperatures in which the surface can heat to over 450°C (850°F) during the day and cool to ~180°C (~300°F) at night. The huge daily temperature changes take place because Mercury’s atmosphere is so tenuous that it is virtually a vacuum and cannot moderate the temperatures like Earth’s atmosphere does. For the same reason, even though much of the atmosphere on Mercury is made of oxygen, you would not be able to breathe there—there just is not enough oxygen to fill your lungs. One breath on Mercury would give you less than one hundred trillionth of the mass of the air you breathe in at sea level on Earth!

Some basic facts about Mercury

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Actual value</th>
<th>Compared to Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>4900 km</td>
<td>38% of Earth’s diameter</td>
</tr>
<tr>
<td>Mass</td>
<td>$3.3 \times 10^{23}$ kg</td>
<td>6% of Earth’s mass</td>
</tr>
<tr>
<td>Mean density</td>
<td>5400 kg/m$^3$</td>
<td>About the same as Earth’s</td>
</tr>
<tr>
<td>Moons</td>
<td>None</td>
<td>One (The Moon)</td>
</tr>
<tr>
<td>Orbital period</td>
<td>88 Earth days</td>
<td>1/4 of Earth’s</td>
</tr>
<tr>
<td>Rotation period (around its axis)</td>
<td>59 Earth days</td>
<td>59 times longer than Earth’s</td>
</tr>
<tr>
<td>Length of one day (sunrise to sunset)</td>
<td>176 Earth days</td>
<td>176 times longer than Earth’s</td>
</tr>
<tr>
<td>Average distance from the Sun</td>
<td>58 million km</td>
<td>0.39 AU (Sun-Earth distance)</td>
</tr>
<tr>
<td>Magnetic field</td>
<td>Yes</td>
<td>Weaker than Earth’s</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>Extremely tenuous</td>
<td>Virtually a vacuum in comparison</td>
</tr>
<tr>
<td>Average surface temperature</td>
<td>170°C (330°F)</td>
<td>150°C (270°F) hotter than Earth’s</td>
</tr>
</tbody>
</table>
MESSENGER is an unmanned NASA spacecraft that will be launched in 2004 and arrive at Mercury in 2009. It is only the second spacecraft to study Mercury, and the first since the 1970s, when Mariner 10 rendezvoused with the planet. MESSENGER is the first spacecraft to observe Mercury from orbit and not just fly by. Its observations will allow us to see the entire surface of the planet for the first time.

The acronym MESSENGER stands for MErcury Surface Space ENvironment, GEochemistry and Ranging. The name highlights the scientific topics of the mission, but it is also a reference to the name of the ancient Roman messenger of the gods, Mercury, after whom the planet is named.

Sending a spacecraft to Mercury is complicated. The planet is so close to the Sun that MESSENGER will be exposed to up to 11 times more sunlight than it would in space near Earth. To prevent the intense heat and radiation from having catastrophic consequences, the mission has been planned carefully to make sure the spacecraft can operate reliably in the harsh environment. To rendezvous with Mercury on its orbit around the Sun, MESSENGER will use a complex route: it will fly by Venus twice and three times by Mercury before entering into orbit around Mercury.

The MESSENGER spacecraft is built with cutting-edge technology. Its components include a sunshade for protection against direct sunlight, two solar panels for power production, a thruster for trajectory changes, and fuel tanks. The instruments aboard MESSENGER will take pictures of Mercury, measure the properties of its magnetic field, investigate the height and depth of features on Mercury’s surface, and in general observe the properties of the planet and its space environment in various parts of the electromagnetic spectrum and via particle radiation studies.

During its mission, MESSENGER will attempt to answer several questions about Mercury. How was the planet formed and how has it changed? Mercury is the only rocky planet besides Earth to have a global magnetic field; what are its properties and origin? What is the nature and origin of Mercury’s very tenuous atmosphere? Does ice really exist near the planet’s poles?

Mercury is an important subject of study because it is the extreme of the terrestrial planets (Mercury, Venus, Earth, Mars): it is the smallest, one of the densest, it has one of the oldest surfaces and the largest daily variations in surface temperature—but is the least explored. Understanding this “end member” of the terrestrial planets holds unique clues to the questions of the formation of the Solar System, evolution of the planets, magnetic field generation, and magnetospheric physics. Exploring Mercury will help us understand how our own Earth was formed, how it has evolved, and how it interacts with the Sun.

For more information about the MESSENGER mission to Mercury, including information on the spacecraft design, instruments and discussion of science background and goals, visit http://messenger.jhuapl.edu/
Introduction
Tonight, if you look up into the sky, you’ll see the same bright lights that your ancestors admired, named, and used to find their way when they were lost, or to explain unusual events in their lives. With today’s technological imaging, you can better see those stars, planets, moons, comets, meteors, asteroids, and now even artificial satellites.

As humans, we have always strived to increase our knowledge about the Universe. For centuries, we explored from the comfort of our own planet, Earth, where we could breathe air, sit on firm land, take notes on stone, paper, or computers, and teach others what we know through our writing and speaking. When we first ventured out into space in the mid-20th century, we had to change the way we gather, store, and share information. Now it would be done with machines that help us "see" in increasingly sophisticated ways, as we explore more deeply away from our home planet.

One of the ways we have learned to gather new information about other planets is to send out data-gathering instruments that are sensitive to a variety of influences. These instruments have to endure the stress of leaving the Earth’s comfortable atmosphere atop a rocket, and continue to function under the most hostile conditions imaginable: the cold vacuum of space, the intense heat and radiation from the Sun, and the quick changes between the two as a spacecraft speeds along at thousands of miles per hour.

We go into space, to the Moon, and now to planets such as Mercury, even in the face of great risk, to push our problem-solving capabilities beyond current limits, and explore uncharted regions of the Universe. It is the nature of human exploration. We also do this because the potential benefits are too great to ignore. Indeed, it is only if we continue to explore beyond our reach that we will be able to better understand our own world, and address challenges that face us here on Earth.

MESSENGER Education and Public Outreach Program
One of the most recent of our instruments investigating other worlds in the Solar System is MESSENGER, the MErcury Surface, Space ENvironment, GEochemistry and Ranging mission, designed to study the planet Mercury. It will be launched in 2004, enter into orbit around Mercury in 2009 and observe the planet and its space environment for one year.
The goals of the mission not only include gathering massive amounts of information about the mysterious planet Mercury, but to also take the nation along for a thrilling ride of exploration. Indeed, bringing a sense to the general public of how mission planners overcome challenges and achieve triumphs has been taken on as a national responsibility.

The Education and Public Outreach (E/PO) team assembled to meet this challenge is an extensive network of individuals from the following organizations: American Association for the Advancement of Science (AAAS); Carnegie Institution of Washington Carnegie Academy for Science Education (CASE); Center for Educational Resources (CERES) at Montana State University (MSU) – Bozeman; Challenger Center for Space Science Education (CCSSE); Johns Hopkins University Applied Physics Laboratory (JHU/APL); NASA’s Minority University-Space Interdisciplinary Network (MU-SPIN); National Air and Space Museum (NASM); Science Systems and Applications, Inc. (SSAI); and Southwest Research Institute (SwRI).

To meet the goal of education and public outreach on a national level, a comprehensive set of activities coordinated with MESSENGER events has been designed to enliven education from kindergarten through college and to excite the public. These activities include education materials development, teacher training through an educator fellowship program, unique student investigations related to the MESSENGER mission, a television documentary, museum displays, and special outreach to underserved communities and minority students.

A few examples of these exciting initiatives include:

**MESSENGER Education Module Development**

A set of MESSENGER Education Modules (MEMs) will be produced in connection with the mission. The Modules are standardized presenter’s packages that can be used by educators and teacher trainers. They consist of a diverse mix of educational materials and multimedia resources and are intended for use nationwide in preK-12 classrooms. At the core of the MEMs are concept-based, inquiry-driven lessons intended for use in classrooms nationwide. These standards-based lessons address Solar System science, planetary observations through history, and the engineering associated with building and sending a spacecraft to another world. Carnegie Institution of Washington Carnegie Academy for Science Education is overseeing the development of the grade level preK-1 and 2-4 components. Challenger Center for Space Science Education is developing the grade level 5-8 and 9-12 components.
The MESSENGER Fellowship Program

The MESSENGER E/PO Program will sponsor a nationwide teacher training initiative whereby a cadre of Fellows—master science teachers at the elementary, middle, and high school levels—will receive training on the MEMs and conduct educator workshops nationally, training up to 27,000 grade preK-through-12 educators over the mission lifetime. Challenger Center for Space Science Education is responsible for developing and managing the Fellowship program.

Journey through the Universe Program

Training for educators on the MEMs will also be conducted as part of Challenger Center’s Journey through the Universe program. Established in 1999, the program reaches out to underserved communities nationally, providing programming for teachers, students, and families. For more information, visit: www.challenger.org/journey.

MESSENGER Online

An extensive Web environment has been developed for the MESSENGER E/PO Program. Some aspects of the Web site include online science courses and classroom materials for preK-12 teachers. Among other services, the Web site will allow download of MEMs by an international audience.
Teaching about the MESSENGER Mission—MESSENGER Educational Pedagogy

For the purposes of teaching about the MESSENGER spacecraft and mission design, and for making that information relevant to the lives of young people today, we have created an educational program, which parallels the 10-year MESSENGER mission. We start from the notion of sending a human-made probe to the closest planet to the Sun, and we ask students to consider the processes and humanpower needed to complete such a mission.

We continue by introducing students to different branches of science that must be studied for an understanding of the data retrieved from the spacecraft. These include astronomy, physics, chemistry, geology, thermodynamics, magnetism, and optics, to name just a few.

We extend beyond the sciences to make interdisciplinary connections to, e.g., mathematics, technology, social studies, and all aspects of literacy to strengthen students’ abilities across the curriculum, helping them discover cultural as well as scientific understandings of the planets, the Sun, and the skies.

We develop students’ literacy of science by using appropriate scientific vocabulary and concepts, while also helping them build their literacy through science, as we use inherently fascinating scientific phenomena as a means of promoting reading and writing.

We launch design challenges that motivate students to build systems, design experiments, discover improved ways of doing things, and observe the world around them, in an effort to provide them the required context to best learn the skills they will need throughout life, in all areas.

We approach science education by asking essential questions that drive the quest for knowledge, by giving students ample opportunities to explore situations that embody important scientific ideas, and by encouraging them to express their ideas about what they are exploring. Teachers are then able to choose appropriate ways of helping students test their ideas, to discover which ideas apply more widely and may be more scientifically-derived than what they had previously thought.
We design activities that require first-hand observations as well as in-depth study of existing data. In both cases, students are allowed to develop ideas more fully as they work through their own creative thinking and problem-solving, rather than through rote memorization. It is essential that children change their own misconceptions as a result of what they find themselves, not merely by accepting other ideas they have been told are better than their own.

We encourage creativity and thinking outside the box, while making sure that national science standards are directly addressed in every lesson. Children learn science best through a process that helps them link ideas and develop new concepts. We make full use of science process skills (observing, measuring, hypothesizing, predicting, planning and carrying out investigations, interpreting, inferring, and communicating) to help them make sense of the world around them. In addition to traditional summative evaluations at the end of a lesson, we offer forms of formative assessment throughout the teaching process, so that the teacher is aware of students’ evolving ideas and skills. Furthermore, this information is an integral part of effective teaching, since it can significantly change the direction of a given lesson to better address problems or misconceptions that persist.

In general, we provide a context for understanding the significance of scientific ventures and engineering feats such as the MESSENGER mission, and we open the door to students who will both understand and build the future.

The MESSENGER Education Themes and MESSENGER Stories
The MESSENGER Education Modules will concentrate on the following themes:

▲ Comparative Planetology – Understanding the planets as individual worlds and as part of a larger family by studying their similarities and differences. It is a look at what we know about our family of planets, and what we do not know. It also addresses what is currently known about Solar System formation and evolution. MESSENGER stories relevant to this theme include what Mercury tells us about the family of planets, and how MESSENGER observations are specifically framed to change our view of the Solar System.
The Solar System Through History – How we have come to know what we know about the Solar System. The student will explore the Solar System through the eyes of, and resources available to, past generations. MESSENGER stories relevant to this theme include different cultures’ views of Mercury through history as a case study of planetary observations; and how MESSENGER science and engineering stands on the shoulders of past generations.

Framing Pathways to Answers: The Scientific Process in Action – An exploration of the scientific process as applied to two fundamental types of problems:

- Solving engineering and design problems within a context of constraints.
- Exploring a phenomenon of nature by asking a question of that phenomenon, framing experimental pathways to acquire data, and interpreting that data in the context of a greater body of knowledge.

This thematic overview also places research and exploration in a human context. Relevant stories within this theme include solving MESSENGER engineering problems to make the mission possible, and framing experimental pathways to do MESSENGER science.

Each theme defines an Education Module that is a story in one to three Units, each like a chapter of a book. Each Unit is associated with its own sub-story told though as many as three Lessons at each of four grade levels: PreK-1, 2-4, 5-8, and 9-12. As an example, the "Framing Pathways" Module includes a Unit on Staying Cool and another Unit on Spacecraft Design. Besides the Lessons, a Unit might also contain design challenges — tasks intended to give the students the opportunity to put the concepts learned in the Lessons into an innovative use by challenging the students to come up with an experimental design addressing a specific engineering problem.

An example of a MESSENGER Education Module:
Framing Pathways to Answers: The Scientific Process in Action

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<tr>
<th>PreK - 1</th>
<th>Lesson 1</th>
<th>Design Challenge</th>
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</thead>
<tbody>
<tr>
<td>2 - 4</td>
<td>Lesson 1</td>
<td>Design Challenge</td>
</tr>
<tr>
<td>5 - 8</td>
<td>Lesson 1</td>
<td>Lesson 2</td>
</tr>
<tr>
<td>9 - 12</td>
<td>Lesson 1</td>
<td>Lesson 2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PreK - 1</th>
<th>Lesson 1</th>
<th>Lesson 2</th>
<th>Lesson 3</th>
<th>Design Challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 - 4</td>
<td>Lesson 1</td>
<td>Lesson 2</td>
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<td>Design Challenge</td>
</tr>
<tr>
<td>9 - 12</td>
<td>Lesson 1</td>
<td>Lesson 2</td>
<td>Lesson 3</td>
<td>Design Challenge</td>
</tr>
</tbody>
</table>
Connections to Science Education Standards and Benchmarks

MESSENGER Educational Modules (MEMs) focus on not only what science is taught but also how science is taught. Many state and local districts use National Science Education Standards and Project 2061 Benchmarks as the foundation for their science curriculum. The MESSENGER Modules are mapped to the standards, with a standards matrix found in each Unit. The MEMs emphasize activities that encourage students to ask questions and become deeply involved in work that is based on their own ideas. MEMs stress inquiry-based, process-driven approaches to science education.
HOW TO USE A LESSON

Each Lesson within the MESSENGER Education Units has been instructionally designed with a variety of components, each serving a specific function as a means of delivering a comprehensive and powerful inquiry-based lesson. This document offers teachers an explanation of each section in a Lesson.

Lesson Components:
▲ Title and Grade Level of Lesson – Provides a general idea of the lesson theme for a given grade level range.
▲ Duration of Lesson – Provides anticipated duration of the lesson in the classroom.
▲ Lesson Summary – After reading the summary, the teacher should understand the underlying principles of the lesson, including how it fits into the overall theme of the Unit.
▲ Essential Question – This overarching question provides teachers with the main focus of the lesson. Students should be able to answer this question at the completion of the lesson.
▲ Objectives – These objectives are measurable outcomes expected of students.
▲ Concepts – The lesson should provide insight and provoke questions about fundamental concepts.
▲ MESSENGER Mission Connection – Each lesson relates to a specific aspect of the MESSENGER mission to Mercury. This section explains the reason why this lesson is included in the MESSENGER Education Module (MEM).
▲ Standards & Benchmarks – The National Science Education Standards and the American Association for the Advancement of Science Project 2061 Benchmarks are the driving force behind these lessons. Each lesson addresses 1-3 core standards and benchmarks, and may address many more related standards and benchmarks.
▲ Science Overview – This section provides the teacher with background information essential to facilitating the activities in the lesson. Enough information is provided so that answers to most of the questions the teacher (or students) may have can be found in the Science Overview. For a more comprehensive discussion of the topics in the Overview, a science textbook is an appropriate source. The teacher can choose to read or skim as much of this material as they find necessary, which may depend on their personal science background. This section is not intended to be used by the students, although sections may be shared with the students at the discretion of the teacher.
▲ Lesson Plan – The lesson description provides specific instructions for the teacher. It includes everything the teacher requires to carry out the lesson. Teachers are strongly encouraged to adapt the procedures to best meet their needs in their own classroom. (See Lesson Plan description below.)
Internet Resources & References – A list of web sites that will enhance or clarify the concepts within each Lesson. These include the MESSENGER web site, National Science Education Standards, Benchmarks for Science Literacy, and any web sites that may aide in understanding the Science Overview.

Student Worksheets – Worksheets may be copied and given to individual students. They supply the students with everything they need in order to perform the activities. There may be additional worksheets that apply what they have learned from the activity to other concepts within the lesson. Some worksheets are optional or offer challenges for advanced students; these worksheets are clearly marked.

Answer Keys – Includes correct or suggested answers for teachers. Used to aid in assessment.

MESSENGER Information Sheet – This can be copied and handed out to the students to provide them with background information about the MESSENGER mission to Mercury.

Each Lesson Plan includes the following:

Preparation – Suggests classroom organization, varied student groupings, set-up strategies, materials distribution, etc.

Materials – Lists the supplies, books, etc. needed by the teacher and students.

Warm-up & Pre-assessment – Strategies for getting students interested and motivated to participate in a lesson. Suggests ways to find out what students already know, including misconceptions they may have. (May occur in warm-up, homework discussions, or separately).

Procedures – Steps to be followed by the teacher to conduct an activity.

Discussion & Reflection – A guide to activities or discussion topics to help students better understand what they have been learning, anchor that new learning into existing knowledge, and to clarify any issues.

Lesson Adaptations (in Special Education, Talented and Gifted, and English as a Second Language Programs) – Offers variations on the Lesson Plan to accommodate the needs of these students. Some lessons do not have adaptations.

Extensions – The extensions allow students to develop higher and more complex levels of understanding concerning concepts and information that they have learned. Some lessons do not have extensions.
▲ *Curriculum Connections* – Describes the nature of the relationship between the science lesson and other traditional subject areas such as math, history, geography, art, music, English, physical education, technology, foreign languages, etc.

▲ *Closing Discussion* – Provides strategies for ending a lesson in a meaningful way for the students.

▲ *Assessment* – Suggests verbal, written or performance-based assessment strategies to verify progress during the lesson or activity.

In addition, Teaching Tips boxes appear throughout the Lesson Plan.
COOLER IN THE SHADOWS
Designing to Stay Cool

Lesson Overview

Lesson Summary
Students will make inferences about the cause of shadows, by observing and making their own shadows in the sun. Many properties of shadows (such as heat and brightness of light) will also be identified firsthand as the students conduct simple experiments to observe changes that are comparable to those experienced by the MESSENGER spacecraft in its voyage to and around Mercury.

Objectives
Students will be able to:
• discover patterns in the behavior of sunlight, temperature, and shadows
• gain an understanding of how shadows form and the factors that influence the shape and size of a shadow
• explain the difference between a shadow and a reflection
• understand that light travels in a straight line
• begin to understand why shadows outdoors are different at different times of the year
CONCEPTS

- Sunlight and other types of light form shadows.

- Shadows form because light travels in straight lines.

- Light cannot pass through some materials and this leads to the formation of shadows.

- Shadows can change position and shape and size depending on the position of the object in relation to the position of the light source.

- Darkness is the absence of light.

MESSENGER Mission Connection

The generation of heat by sunlight is also why shadows are important for the MESSENGER mission to Mercury. Because the spacecraft will be very close to the Sun, it will receive much more intense sunlight than we get on Earth. To reduce the temperatures in the probes, a sunshade is included on the craft. The spacecraft is oriented so that the shade always faces the Sun, and the sensitive instruments used to make observations of Mercury are always in shadow.

WARNING

Do not look directly at the Sun!

This lesson is about the Sun and sunlight, but be sure to remind students frequently never to look directly at the Sun! Looking for even a few seconds can cause permanent damage to the eyes, and longer exposure can cause blindness. Note that sunglasses do not provide an adequate safeguard against looking directly at the Sun.
STANDARDS & BENCHMARKS

NATIONAL SCIENCE EDUCATION STANDARDS

K-4 Standard D2b Objects in the Sky
◆ The sun provides the light and heat necessary to maintain the temperature of the Earth.
  (From the narrative: "As they [students] observe changes, such as the movement of an object's shadow during the course of a day, and the positions of the sun and moon, they will find patterns in these movements.")

K-4 Standard B31 Light, Heat, Electricity, and Magnetism
◆ Light travels in a straight line until it strikes an object.

BENCHMARKS FOR SCIENTIFIC LITERACY (AAAS PROJECT 2061)

4E (K-2)
The sun warms the land, air and water.
The Nature of Shadows
Shadows are evidence that light travels in straight lines from its source. If the path of light is blocked by an object, then the light cannot reach the surface behind the object, so it remains (relatively) un-illuminated, in contrast to the more brightly lit area around it. Thus a shadow may be defined as the lack of illumination rather than an object in its own right.

Nevertheless, common phrases and stories, as well as repeated experience, lead us to think of shadows as things. For example, we talk of 'casting a shadow', or of 'our shadow following us', while shadows take on a separate identity in cartoons and stories such as Peter Pan. Even for those who have a scientific understanding of shadow production, the appearance of shadows makes them seem like objects. For children who have not formed an understanding of light travel, this appearance can overwhelm any attempt to teach the scientific explanation.

Shadows are important in our daily lives. It is, after all, what separates night from day: night comes in an area when the Earth rotates around its axis so that the area in question is not facing the Sun but is in the shaded side of the Earth.

The Relationship Between Light, Heat and Shadows
Sunlight heats the objects it illuminates. Because there is less light in the shadows and in the shaded parts of objects, the heat generated by the light in these areas is also less. That is why it is cooler at night than it is during the day, and why the temperatures in the shade are lower than in sunlight during the day.

Young students require many different experiences in various contexts to successfully form a conceptual knowledge of light. Take into account the children's own ideas, not only at the beginning of each experience but also at intervals during an activity. It is important to plan investigations with the children, using their ideas as a starting point. For instance if children believe that shadows can only be produced by the Sun, have them test this idea. For example, by shining a flashlight and/or a candle on a toy figure, a child can see that a shadow is indeed produced by other kinds of light as well as by the Sun.

Generally children are more aware of their own shadows than the shadows of objects. Some children confuse shadows with reflections and draw a colored shadow detached from the object casting the shadow. Many youngsters know that shadows can be produced by sunlight, but very few can explain what happens to light when a shadow is formed.
Lesson Plan: Activity 1: Shadows

In this activity, students will explore making and tracking shadows of different objects over the course of the day to discover patterns in the behavior of sunlight, temperature and shadows.

Preparation

Assemble the needed materials [e.g. in the center of each table, on each student’s desk, etc.]. If the students are working in groups it is useful to provide the materials for each group in a bucket, tub or plastic bag so that the materials are easily carried outdoors.

Teaching Tip

Do this activity when the sun is relatively high in the sky, either near the beginning or the end of the school year. You’ll also want to measure sun shadows at least twice and perhaps three or four times during the day to see how they vary. It is best to conduct this shadow activity a day or two before reading the book, Bear Shadow, (Activity 2 of the Cooler in the Shadows lesson) and making the map of Bear’s neighborhood (Activity 3).

Materials

Per class:
• Two large classroom thermometers or temperature strips
• yardstick
• large coffee can of soil or stones holding a 12-14” stick

Per group:
• large pieces of paper
• chalk
• an umbrella
• pencils
• markers
• paints
• various objects such as hoops, lace, balls, etc.
• large, flat sheet of cardboard, poster board, or other heavy paper (at least 2’ x 3’)
• compass
WARM-UP & PRE-ASSESSMENT

Find out from the children what they think or know about the nature and origin of shadows. Use some of the following questions to spark the conversation:

- What are shadows?
- Can you pick up a shadow?
- Can your shadow become detached from you? If so, how?
- If your shadow is detached from you, could it be sewn back on, like Wendy did with Peter Pan's shadow?
- When do you have a shadow? What needs to be true before you have a shadow?
- Why does there have to be a bright light? What does the light do?
- Where does your shadow appear? Is there any connection to where the light is coming from?
- Can you ever have more than one shadow? How?
- If a shadow forms because you block the light, how is it that you can still see something that is in the shadow?

Teaching Tip

This exercise (or something similar) can be used when children disagree about the properties of shadows, such as their size and shape. It is best if such an exercise (or small scale experiment) arises from the children’s discussion and/or specific predictions, statements or disagreements. The children might well devise similar experiments involving, say, themselves and the sun or a flashlight and toy figure. It is equally important to follow the experiments with a discussion of what was discovered. The basic pattern here is the well-known POE - Predict, Observe, Explain. This method is most likely to be effective, however, when the children co-construct both the prediction and explanation through discussion, rather than by mandate from the teacher.
PROCEDURES

1. Divide the class into 2 teams: The Shadow-Makers and the Shadow-Trackers. (You may want to have 2 trackers per maker, so that they can compare observations.)

2. Explain the roles to be played, and how important it is that everyone participate.

3. Set up a system so you can record the temperatures on a summary chart on the board to show all the students at the end of the activity.

4. Have the Shadow-Makers lay down a piece of poster board, on which they place some objects in the sun, either outside or on a window sill.

5. Have some Shadow-Trackers trace the objects’ patterns on the poster board every hour.

6. Have other Shadow-Trackers measure the temperature of the stationary objects and the shadow they create every hour, and record it, with the time of day, next to the tracing on the poster board.

7. Have the Shadow-Trackers try to draw what the objects and their shadows would look like if they could take a "snapshot" that would freeze the moment in time, like a photograph does.

8. Outside in the sunlight, mark a place in chalk for a Shadow-Maker to stand and hold at arm’s length one of the objects that was placed on the ground in the first part of the investigation. Have a Shadow-Tracker trace the shadow below. (Later you will compare the traced images of the objects.

Teaching Tip

When actual temperatures are not possible to measure, have the students place their hand on the object and see if they can compare how it feels in or out of the sunlight, or compared to another object in or out of the sunlight. Use "hotter" or "cooler" to describe the different surfaces of the objects, in or out of direct sunlight.

You may also want to have the students place a small object in the shade, keeping it there by moving it with the moving shadows through the day, measuring its temperature (which should remain steadily cooler than the surface of the larger object in direct sun).
**Discussion & Reflection**

Summarize the students’ observations on a chart set up for the whole class to see. Ask what kinds of conclusions they can make about the nature and behavior of shadows, and of objects found within those shadows.

Using the traced shadows of the objects you used both on the ground and suspended in the air, ask if there are any differences. Then have the students imagine sitting in a basket under a big tree. Would there be shade? In the tree’s shadow, would it be hot or cool? Now have them imagine sitting in that basket suspended high in the air. Is there any shade? Would it be hotter or cooler there than under the tree?

Point out that when objects (such as airplanes and space rockets) move up very high into the sky, they don’t have shade anymore from the Sun, so we have to keep them – and any people inside – from getting too hot from being in the sunlight all the time.

Tell the students that we are sending up a rocket into space with a little spacecraft called MESSENGER, and that since it won’t have any shadows to rest in when it gets too hot, we had to build something to give it a shadow all the time.

Ask the students if they can show you one of the objects they used in the activity that would be a good shade for a small spacecraft. If necessary, stand under the umbrella and ask them if you are in the light or in the shade. If using a lamp, let a student move the lamp. Move the umbrella to keep your face shaded. If outside, show how you can easily keep up with the movement of the sun to keep your face out of the light. Tell them that this is exactly how they’re going to keep MESSENGER from getting too hot while it’s up in space.
Lesson Adaptations

- For students with hand-eye coordination problems, have them work as a team to trace shadows on for the Shadow Trackers, or give them Shadow-Making roles.

- For non-readers of letters or numbers, have them mark the thermometer’s mercury level with a post-it or a crayon, so that the teacher can then read it and record it for them. See also Teaching Tip about using the hand to compare warmer or cooler temperatures.

Curriculum Connections

- Math / Measurement: Reading thermometers

- English: New vocabulary words to introduce into daily usage: shadow, shaded, sunshade, attached/detached, light intensity, temperature, exposure, illumination etc

- Art: Tracing images, drawing in details or color after outlining, drawing an object with its shadow when illuminated from different directions

Assessment

Have students describe (orally or in writing as appropriate) the experiment, report data, and come to a conclusion about how shadows form and how the temperature varies in sunny or shaded areas.
Lesson Plan: Activity 2: Bear Shadow

In this activity students learn about shadows using literature-based discussion and experiences.

Warm-up & Pre-assessment

Review what students may have learned about shadows in the previous lesson or prompt a brief discussion based on some of the following questions:

- What are shadows?
- What does a shadow do?
- When do you have a shadow? Give some examples.
- If a shadow forms when you block light, why can you still see something in a shadow?

Materials

- Bear Shadow by Frank Asch

Procedures

1. Organize the students into a reading area

2. Read Bear Shadow by Frank Asch, either individually or as a participatory exercise. In this story, a bear attempts to escape a shadow that seems to be chasing him. You might guide this discussion by asking questions based on the Warm-up, such as:
   - What did we just discuss about shadows that makes the book funny?
   - Why did Bear’s shadow disappear when he hid behind a tree?
   - Why did the shadow disappear when Bear buried it? What do you think about that?
   - What makes a sun shadow fall one direction at one time and another direction at a different time of day?
   - What else do you have to say about shadows?

3. Use the responses to help the children shape activities through which they will discover the answers to their questions.
Teaching Tip

If you have already begun the study of shadows and have measured sun shadows (Activity 1-Shadows above) at least once, your discussion of Bear Shadow will be more specific. In addition to the kinds of questions above, you can, for example, discuss the time of day when the various events occur and the direction Bear’s shadow will fall at these times.

Discussion & Reflection

• Is your shadow always the same size (and/or shape) as you?
• Under what conditions does the size/shape of your shadow change?
• What factors might affect the size or shape of your shadow? How would it be affected?
• How could you test if your answer is right? [Alternatively, if several class members are offering different answers: How could we decide whose idea produces a better explanation?]

• Remember the MESSENGER spacecraft we talked about? [If you did not do Day 1, tell the students that we are sending up a rocket into space with a little spacecraft called MESSENGER. Since it won’t have any shadows to rest in when it gets too hot, we had to build something to give it a shadow all the time; it looks like an umbrella and is called a sunshade.]

• Well, we’re putting all sorts of cameras on MESSENGER to take pictures up in space! We don’t want any of the cameras to break or to get hurt by all the hot sunlight, so when do you think is the safest, best time to use the cameras?

Assessment

Use the answers to the questions above as the basis of your assessment.
Curriculum Connections

- Reading and Listening
- Reasoning and Logic Development
- Art

Lesson Adaptations

- Encourage students to experiment for a minute or two to test out some of their theories and ideas during discussions. Then have them return to the group and decide if they want to maintain their original comments, or change them to reflect what they discovered in their mini-experiments.
Lesson Plan: Activity 3: Making Scale Model Shadows of Bear's Neighborhood

In this lesson, students will construct a model neighborhood to demonstrate their understanding of shadows. Many questions and suggestions for variants on the activities are presented to allow you to tailor this lesson to your particular needs. It is best to make the model of Bear's neighborhood when the sun is relatively high in the sky, either near the beginning or the end of the school year. You'll want to measure the sun shadows with students at least twice, and perhaps three or four times during the year, to see how they vary with the time of year.

Preparation

Ideally, you will have completed Activity 1: Shadows above or have measured sun shadows in some other context, so your discussion can be more directed. You may, for example, discuss the time of day when the various events in the book occur, and the direction in which the Bear's shadow will fall at these times.

Organize the materials for the activity. Clear a space in the room if you cannot construct your model neighborhood outdoors, or identify and reserve, if necessary, a place on the playground to build the model.

Teaching Tip

When you construct Bear’s imaginary neighborhood on the playground or in a field, do it away from the potential shadow of the school building! For young children, it's best to construct the model outdoors where the position of the Sun is determined by the Earth's rotation, tilt, and location in its yearly revolution around the Sun.

<table>
<thead>
<tr>
<th>Materials</th>
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<tbody>
<tr>
<td>For small 3-D model:</td>
</tr>
<tr>
<td>• some appropriate area in the classroom, art room or other available space, large enough to build a scale model of the neighborhood (about 5x5 feet)</td>
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<tr>
<td>• cardboard</td>
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<tr>
<td>• scissors</td>
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<tr>
<td>• glue</td>
</tr>
<tr>
<td>• cardboard boxes of various sizes to represent buildings in Bear’s neighborhood</td>
</tr>
<tr>
<td>• foil to make the pond and brook</td>
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<tr>
<td>• Model trees or small pieces of shrubs to represent the trees</td>
</tr>
<tr>
<td>• tape</td>
</tr>
<tr>
<td>• pencils, crayons, and markers</td>
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<td>• a bright lamp</td>
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</tbody>
</table>
**Warm-up & Pre-assessment**

- Re-read Bear Shadow by Frank Asch (See Activity 2) and briefly discuss.
- Be sure the students know their compass directions. If necessary, teach them beforehand how to find North on a compass.

**Procedures**

1. Divide students into groups of 3-4.

2. Explain to the students that the class will make a 3-D model of the neighborhood where Bear lives. Use a compass (teacher or students can do this) to find North. The model should show clearly which direction is north, either with an arrow or by orienting a three-dimensional model correctly with respect to the actual directions. Tell them to be sure the map/model includes:
   - Bear’s house
   - the pond where he went fishing
   - the brook he jumped over
   - the tree he hid behind
   - the cliff he climbed
   - the place where he tried to nail the shadow to the ground
   - the place where he dug the hole to bury the shadow

3. Start making the model by asking the students to decide a place for the pond. Once they have made that decision, assign each group a feature to place on the model. Have each group explain the reasoning that led to each placement. There may be disagreements, but the criterion for "correctness" is whether the placement parallels the pictures in the book.

**Materials cont’d:**

For large 3-D map/model to be built outdoors:

- an appropriate place on the school grounds
- six or seven different-sized large cardboard boxes
- scissors
- glue
- duct tape
- pencils, crayons, and markers
- any additional material students [e.g. fallen branches, a broom, a mop, a ladder, a tarp] can use to create landmarks like the tree, Bear’s house, and so on
- A Teddy Bear of appropriate size to represent Bear
- compass
4. When the model is complete, the students will use the thermometers to measure the temperature in the sunlit areas and the shaded areas. Record the temperatures at each location in a chart so that the students can easily see any differences. Ask the students can explain why some areas are warmer or cooler. Help the children conclude that it’s hotter in light than it is in shadow.

Discussion questions may include:

- At what time of the year does the story happen?
- At what time of day did Bear go out to fish?
- At what time of day did Bear try to nail his shadow to the ground?
- At what time of day did Bear try to bury the shadow?
- How long did Bear nap?
- How many windows are there in Bear’s house?
- Which direction does the door of Bear’s house face?

**Teaching Tip**

Some questions might be posed to all students, or to groups, either to answer "immediately” or to direct their thinking during model construction. Some questions may also be used for assessment of the children’s understanding, their attentiveness to the story details, and their reasoning. In all cases, the response to a question should contain an explanation of how the answer was obtained, not just the answer itself.
Sample assessment questions:

- Could Bear see his shadow when he faced the Sun? What about when he turned the other way? If you're not sure of the answer, can you find a way to test it and show me?

- When did Bear lose his shadow? Could you ever lose your shadow? If so, how? If not, why not?

- Why was Bear afraid of his shadow? Are you afraid of your shadow? Why or why not?

- Can your shadow do something without you? Can you do something without your shadow? How?

- Name three places where Bear could not see his shadow. Name three places where YOU can not see your own shadow!

- Could Bear see his shadow on the pond? If so, when? If not, why not? What else could he see in the pond when he looked down into it? [Possible "reflection" discussion, to compare the differences between shadows and reflections, especially for dispelling myths.]
Curriculum Connections

Science:
- Add toy figures and flashlights to the block corner or science area, to allow youngsters the freedom to try out ideas.
- On a sunny day, set out two or three prisms of different sizes and shapes and let the children explore the effect of sunlight passing through the prism.
- Have students draw and measure each other’s shadows with string at different times during the day in order to observe and describe changes in the size of the shadow.
- In general, have materials available for children to freely explore and manipulate.

Art: Have the students color the cardboard cutouts of Bear’s model neighborhood, and then shine a light on them to prove that different colored-shadow will not appear. Explain and show how light is needed to see color, and that the less light that is available, the less one is able to see color. A good demonstration of this is by using a dimmer switch on a stage in the auditorium. Lower the lights until only faint images are visible, then raise the lights to show how colors become more intense with increased light (up to the optimal point), and then can get bleached out when the light becomes too intense.

Lesson Adaptations

Have students set up a dollhouse, accessories and a lamp as the Sun. Hold the lamp at different angles, and ask students to speculate on such questions as:
- What time of day is it for the dolls?
- Where would they want to plant their garden so it gets the most light?
- Where is the coolest part of the house to rest in the middle of summer (assuming they have no air conditioning?)
- In the coldest winter months, where could they sit inside to be warmed by the Sun? What time of day or night would that be?
**Lesson Plan: Activity 4: Creating Shadows of a Model Earth**

Students experiment with making shadows of a three-dimensional object, including a globe, to see how they can alter the size, shape and position of their shadows.

**Teaching Tip**
Remove the lampshade if the light is not strong enough, or if you cannot darken the room sufficiently to make shadows.

**Warm-up & Pre-assessment**
- How can you "make" a shadow?
- Can you make more than one shadow?
- How can you change the size, shape, or position of your shadow?
- Where does the light come from that makes the shadow?
- Can light get around the corner to make a shadow around a corner?

**Materials**
- Lamp with 75-100 watt bulb
- 2 spheres (e.g. ideally a world globe about 12 inches in diameter & a tennis or ping pong ball, but any balls of these relative sizes will do)
- A sheet of 36” white poster board
- 1 toy (1”-2”)
  “Matchbox-style” car truck, or other models of real objects
PROCEDURES

1. Have the children sit in a large circle. Darken the room.

2. Place the lamp on a stool or a file cabinet inside the circle.

3. Hand one ball to a child and have him or her stand in the circle near the lamp, holding the ball at arm’s length. During this time, ask the children to predict what they will see.

4. Ask questions about what the children observe.
   - Is the ball making a shadow? If so how do you know? Where is the shadow?
   - If there is no shadow, why not? Where do you think it should be?

5. Hold a piece of poster board right behind the ball and have students observe its shadow. Discuss with them how they needed something on which to see the shadow. (They may have noticed it on the floor or on the classroom wall before this).

6. Hand a small toy car to another child and have him or her stand about a foot behind the first child and further from the lamp, with the car extended at arm’s length. Ask what the children observe. (NOTE: The first ball should be making a visible shadow on the toy car behind it; adjust the children’s distance if necessary, and use the poster board to emphasize the light difference.)

Teaching Tip

If you want to convey the straight line of light concept, use a string to pull between the lamp and the ball, then behind it to the toy car. Have students observe that the light does not turn left and right and cannot reach behind the solid ball.)
PROCEDURES
7. Exchange the second ball with other objects of different sizes. Ask the children:
   • What happens when the object is much smaller than the ball? Larger?
   • How can the small car get out of the shadow?
   • Have the children predict: If you’re in the car in the shadow, are you cold or hot?
     When you go into light, how do you feel?

8. Place the thermometers in the light near the lamp and in the shadow behind the ball. Record the temperatures.

9. Tell the students now to pretend that the ball is the Earth, and that they are standing on it! Remind them that we are sending up a rocket into space with a little spacecraft called MESSENGER. It will be very far away from Earth. Since it won't have any shadows to rest in when it gets too hot, we had to build something to give it a shadow all the time; that something looks like an umbrella and is called a sunshade.
   • Use a toy car or spacecraft and move it towards the lamp and far from the ball, to show how it gets no shade anymore from the large planet Earth.
   • Ask the students if this model MESSENGER got too close to the lamp, and were left overnight there, how hot would it get?
   • Discuss how MESSENGER's sunshade is like the umbrella, that it keeps most of the light and heat away, so that the cameras under it will stay cooler than if they were out in the sun. Use the temperatures from their experiment to prove this.

10. Record the temperatures on the board. See if the children can identify hotter temperatures by their numbers. Help the children conclude that it’s hotter in the light than in shadow.
**Discussion & Reflection**

Discussion and reflection questions are embedded in the procedures above.

**Assessment**

Reread Bear Shadow. As a class, identify those aspects of the story that are purely fictional and those that “could happen,” paying particular attention to how shadows change during the day. Ask students to discuss how they notice temperatures changing during the day, too. Help them make correlations where appropriate.

For example, ask:

- Where would you want to sit to be coolest when it’s a summer day: in the shadow of a big building or in full sunlight in the middle of a baseball field?
- When it’s freezing outside and there’s snow everywhere, where can you warm up most: in the shadow of a big building or in full sunlight in the middle of a baseball field?

Compare the shadows in Bear Shadow to those students made and tracked in Activity 1. Revisit the discussion questions from the Warm-up and Pre-assessment activity, especially focusing on the last one, "What other questions do you have about shadows?" You could spend time answering the students’ questions, as well as generating ones to be answered in the other lessons of this series.

As a class, create a nonfiction version of the story.
CURRICULUM CONNECTIONS

- **Art:** Have students trace each other’s shadows on the ground at different times of day. Mark the footprints of a child so that he or she stands in exactly the same place at three or four different times. Have another student trace the shadow in a different color each time. Write the exact time in the same color chalk (or draw a clock with the hands pointing to that time). Discuss the movement of the shadows, time of day and the placement of the Sun. Have the students speculate as to what will happen as the Sun sets in the evening. Point out the importance of sunlight when artists decide to paint something outside, and how objects can look different when placed in different lights.

- **Music:** Teach the students the song “Me and My Shadow,” and use it as part of a presentation to parents about what they have learned about shadows and sunlight.
INTERNET RESOURCES & REFERENCES

http://www.sciencenetlinks.com/matrix.cfm

ACKNOWLEDGMENTS

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