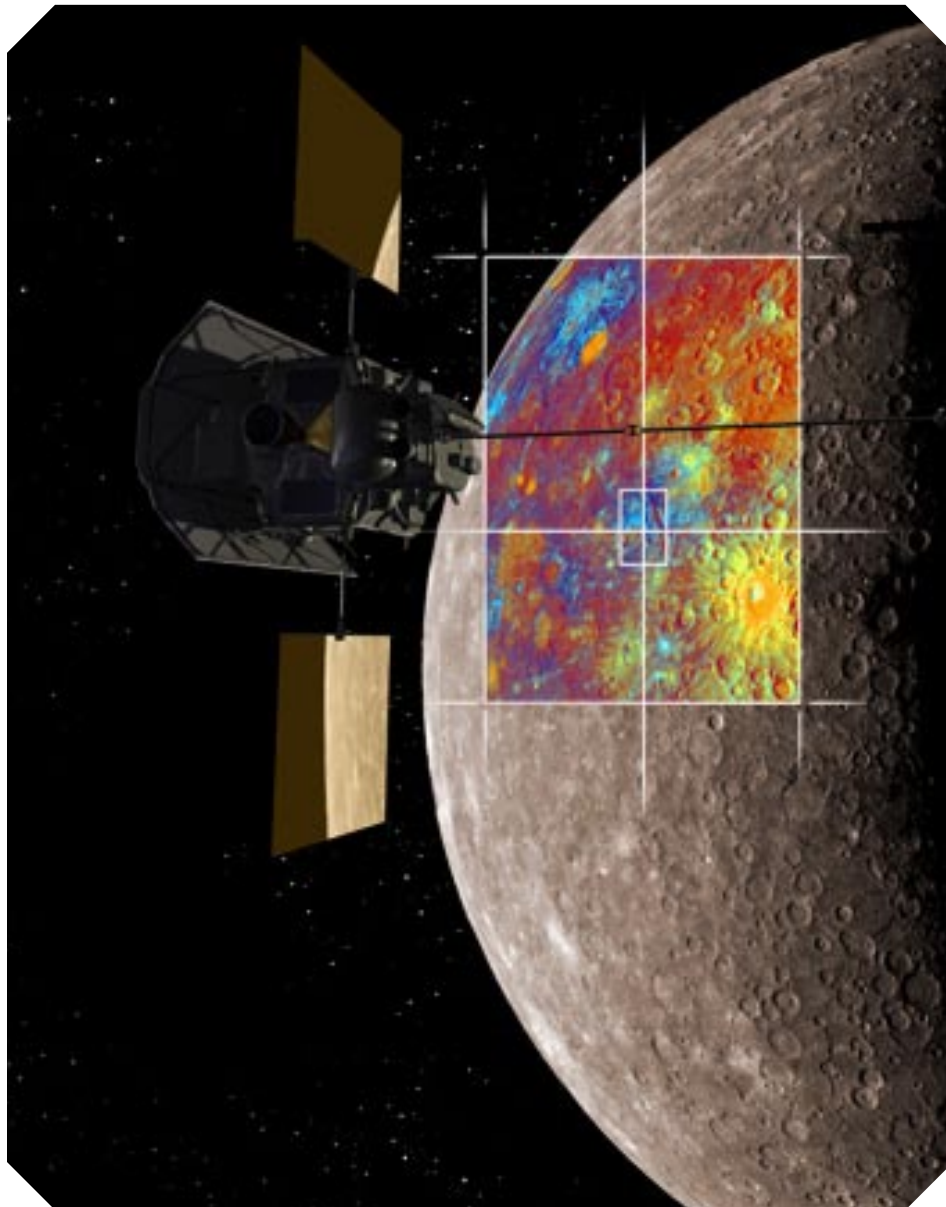


# MESSENGER EDUCATION MODULE

## FRAMING PATHWAYS TO ANSWERS: THE SCIENTIFIC PROCESS IN ACTION



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STAYING COOL

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## MERCURY - THE ELUSIVE PLANET



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 Earth year, Mercury makes over four orbits around the Sun. On the other hand, Mercury rotates slowly around its axis—almost 60 times more slowly than the Earth. The amazing outcome is that a single day (for example, from one sunrise to another) on Mercury takes two of its years.

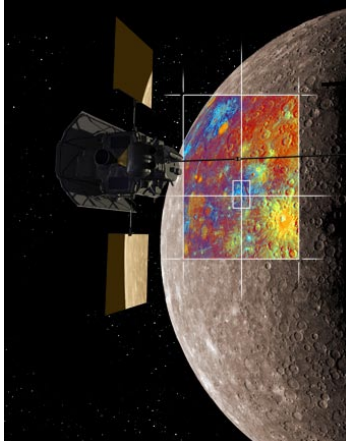
Mercury's orbit around the Sun is much more oval-shaped (eccentric) than the Earth's. This means that unlike the Earth, whose distance from the Sun does not vary much during the year, Mercury's distance from the Sun varies by about 40% during its year. As a result, the size of the Sun seen from Mercury's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

Mercury is the smallest planet in the Solar System, and not much bigger than our Moon. The surface of Mercury looks like the Moon, covered as it is with craters, while its interior is like the 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 the 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 the Earth!

### SOME BASIC FACTS ABOUT MERCURY

CHARACTERISTIC	ACTUAL VALUE	COMPARED TO EARTH
Diameter	4900 km	38% of Earth's diameter
Mass	$3.3 \times 10^{23}$ kg	6% of Earth's mass
Mean density	5400 kg/m <sup>3</sup>	About the same as Earth's
Moons	None	One (The Moon)
Orbital period	88 Earth days	1/4 of Earth's
Rotation period (around its axis)	59 Earth days	59 times longer than Earth's
Length of one day (sunrise to sunrise)	176 Earth days	176 times longer than Earth's
Average distance from the Sun	58 million km	0.39 AU (Sun-Earth distance)
Magnetic field	Yes	Weaker than Earth's
Atmosphere	Extremely tenuous	Virtually a vacuum in comparison
Average surface temperature	170°C (330°F)	150°C (270°F) hotter than Earth's

## THE MESSENGER MISSION TO MERCURY



MESSENGER is a robotic NASA spacecraft that was launched in 2004 and will arrive at Mercury in 2011. 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 the planet. 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 uses a complex route: it flies by the Earth once, Venus twice, and Mercury three times 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 the 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 in the permanently shadowed craters near the planet's poles?

<i>MESSENGER Mission Timeline</i>		
2004	Aug 3	Launch
2005	Aug 2	Earth Flyby
2006	Oct 24	Venus Flyby I
2007	Jun 5	Venus Flyby II
2008	Jan 14	Mercury Flyby I
2008	Oct 6	Mercury Flyby II
2009	Sep 29	Mercury Flyby III
2011	Mar 18	Enter Mercury Orbit

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, visit <http://messenger.jhuapl.edu/>



## MESSENGER EDUCATION AND PUBLIC OUTREACH PROGRAM

### 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 galaxies, 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 kilometers 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. The spacecraft was launched in 2004; it will



enter into orbit around Mercury in 2011 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 (EPO) 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; National Center for Earth and Space Science Education (NCESS); Johns Hopkins University Applied Physics Laboratory (JHU/APL); 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 general public. These activities include education materials development, teacher training through an educator fellowship program, unique student investigations related to the MESSENGER mission, 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) are being produced in connection with the mission. The Modules are standardized presenter's packages that can be used by educators and teacher trainers nationwide in grades pre-K through 12 classrooms. At the core of the MEMs are concept-based, inquiry-driven lessons which 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. The National Center for Earth and Space Science Education is developing the grade level 5-8 and 9-12 components.

#### *The MESSENGER Educator Fellowship Program*

The MESSENGER EPO Program sponsors 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. National Center for Earth and Space Science Education is responsible for developing and managing the Fellowship program.

#### *MESSENGER Online*

An extensive Web environment has been developed for the MESSENGER EPO Program. Some aspects of the Web site include online science courses and classroom materials for preK-12 teachers. Among other services, the Web site allows download of MEMs by an international audience. View the education Web site at <http://messenger-education.org/>.

#### **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, optics, and computer science, 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.

### **MESSENGER Education Themes and MESSENGER Stories**

The MESSENGER Education Modules 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, and what future exploration of the Solar System might entail. 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.

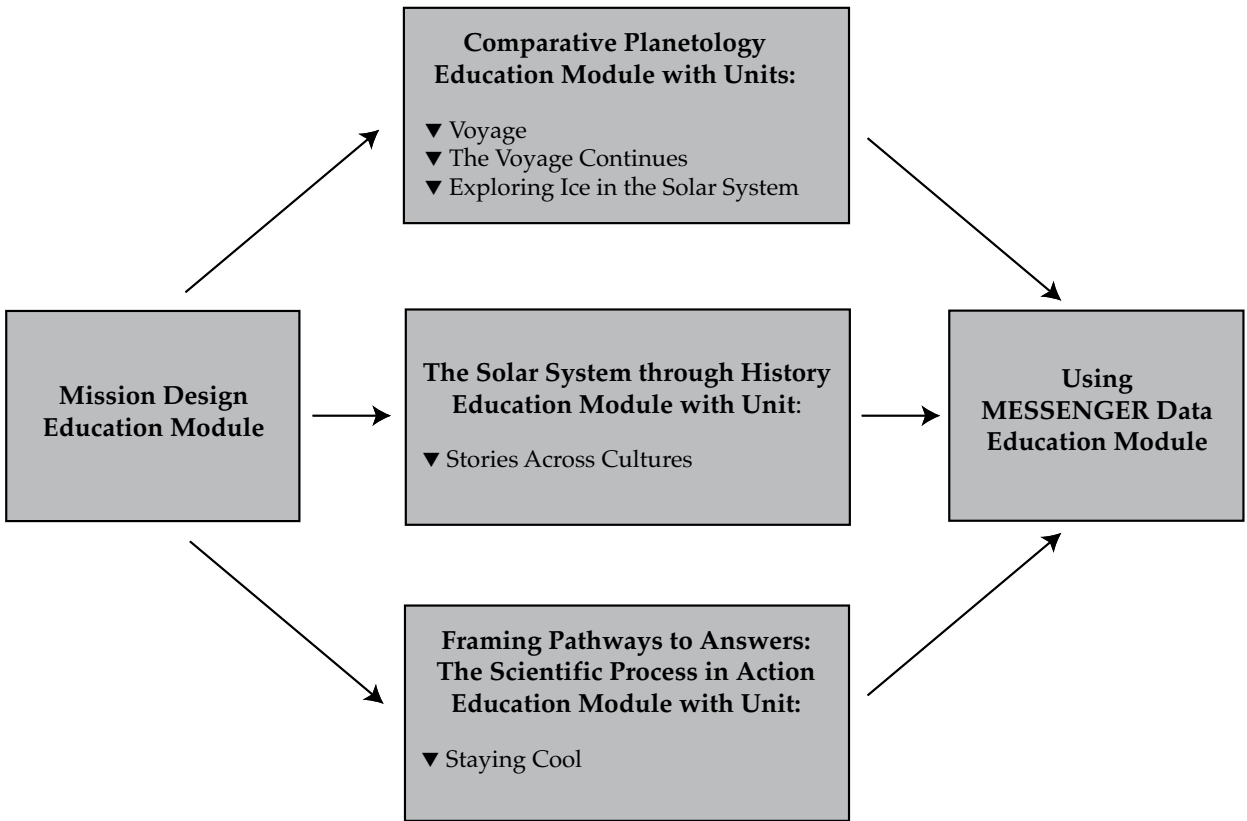
This theme also places research and exploration in a human context. Relevant stories include solving MESSENGER engineering problems to make the mission possible, and framing experimental pathways to do MESSENGER science.

### **MESSENGER Education Modules**

Each theme defines a MESSENGER Education Module (MEM) 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 through as many as three Lessons at various grade levels. There are also two overarching MEMs that carry elements of all the themes at the same time. Figures in the next few pages show the overall structure and the contents of the currently available MEMs.

### **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 American Association for the Advancement of Science Project 2061 Benchmarks as the foundation for their science curriculum. The MESSENGER Education 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.



*Figure: The complete thematic framework for the MESSENGER Education Modules. Two overarching Modules bookend elements concentrating on each MESSENGER education theme. The Modules connected to individual themes include 1-3 Units that tell the story of the Module.*

**Currently Available Education Modules and Units**

*MESSENGER Education Module: Mission Design for Middle and High School*

5-8	Exploring Exploring	Mission: Possible – How to Plan an Exploration of Another World	Look But Don't Touch – Exploration with Remote Sensing
9-12	Exploring Solar Systems Across the Universe	Give Me a Boost – How Gravity Assists Aid Space Exploration	Can You Hear Me Now? – Communicating with Spacraft

*MESSENGER Education Module: Comparative Planetology*

Unit: *Voyage: A Journey Through Our Solar System*

K-2	Making Models to Understand Our Home	A View of Home from the Front Door and from Space	Taking a <i>Voyage</i> Away from Home
3-4	Modeling Patterns and Cycles in Our Lives	Designing a Scale Model of the Solar System	<i>Voyage</i> Through the Solar System
5-8	Our Solar System	<i>Voyage</i> of Discovery	How Far Is Far?
9-12	A Scale Model Solar System	The <i>Voyage</i> Scale Model Solar System	

Unit: *The Voyage Continues*

5-8	Going through a Phase	Round and Round We Go – Exploring Orbits in the Solar System	Where to Look for Life?
	Is There Anyone Out There?	Comets: The Bringers of Life?	Impact Craters – A Look at the Past



*MESSENGER Education Module: Comparative Planetology*

Unit: Exploring Ice in the Solar System

Pre-K - 5	Inquiry Icebreaker: An Ice Experience			
	Lesson 1: Melting and Freezing	Lesson 2: Ice Has Structure	Lesson 3: Ice Is a Mineral	Lesson 4: Ice Floats
	Lesson 5: Ice Flows	Lesson 6: Snow Is Ice	Lesson 7: Layers of Ice	Lesson 8: Life in Icy Places
	Lesson 9: Ice in Space	Lesson 10: Comets	Lesson 11: Investigating Icy Worlds	Lesson 12: Ice in the Shadows

*MESSENGER Education Module: Framing Pathways to  
Answers: The Scientific Process in Action*

Unit: Staying Cool

Pre-K-1	Cooler in the Shadows			Design Challenge: How Can I Keep My Lunchbox Cool?
2-4	Sensing Energy			Design Challenge: How Do You Keep Things from Getting Too Hot?
5-8	Sensing the Invisible – The Herschel Experiment	Snow Goggles and Limiting Sunlight	My Angle on Cooling – The Effect of Distance and Inclination	Design Challenge: How to Keep Gelatin from Melting?
9-12	Star Power – Discovering the Power of Sunlight	Dangers of Radiation Exposure	Cooling with Sunshades	Design Challenge: How to Keep Items Cool in Boiling Water?



## HOW TO USE A LESSON

Each Lesson within the MESSENGER Education Modules 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* – The general theme for the given grade level range.
- ▼ *Duration of Lesson* – 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 Module.
- ▼ *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 additional Web sites that may aid 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 Mission Information Sheet* – 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 & Gifted, and English as a Second Language Programs) – Offers variations on the Lesson Plan to accommodate the needs of these students. Some lessons may 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 may 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* appear throughout the Lesson Plan.

## STAYING COOL: A SHORT OVERVIEW

### Introduction

The MESSENGER Education Modules (MEMs) are diverse packages of educational materials developed for the MESSENGER mission to Mercury. There will be one MEM for each of three basic education themes: Comparative Planetology, The Solar System Through History, and Framing Pathways to Answers: The Scientific Process in Action. "Staying Cool" is one of the Education Units included in the "Framing Pathways to Answers: The Scientific Process in Action" Module. Each Unit contains Lessons at four grade levels (preK-1, 2-4, 5-8, and 9-12). This introduction serves to provide preK-12 educators with an overview of the Unit's contents.

### The MESSENGER Module Framing Pathways to Answers: The Scientific Process in Action

This Module concentrates on how the scientific process can be 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 theme also places research and exploration in a human context. Relevant MESSENGER stories include:

- ▼ Solving MESSENGER engineering problems
- ▼ Framing experimental pathways to do MESSENGER science [the MESSENGER science questions, with emphasis on the process]

### Education Unit: Staying Cool

The focus of this Unit is to examine how science can be used to solve problems related to sunlight, heat, and staying cool in a hot environment. MESSENGER will operate in and explore the high-temperature, high-radiation environment near Mercury. It needs some of the sunlight and high-energy particle radiation to meet the scientific goals of the mission, but too much of either of these can be quite disastrous to the instruments and other components of the spacecraft.



The story of “Staying Cool,” regardless of grade level, unfolds through a story constructed around three questions:

- ▼ How can we study Mercury? [Answer: using light and particle radiation both reflected and emitted from Mercury.]
- ▼ Are there any problems we might face? [Answer: too much light and particle radiation can be dangerous.]
- ▼ Are there ways to solve these problems? [Answer: we can use a variety of means to stay cool.]

Each grade level component of the “Staying Cool” Unit consists of one to three Lessons. Each Lesson addresses one of the essential questions above. As an example, the grade 5-8 component begins with the Lesson “Sensing the Invisible: The Herschel Experiment,” in which students recognize that we can study Mercury in light reflected from its surface and the heat (infrared light) it gives off. Lesson 2, “Snow Goggles and Limiting Sunlight,” provides the realization that while we study Mercury in light, too much light and heat can pose a danger to the spacecraft. In Lesson 3, “My Angle on Cooling: Effect of Distance and Inclination,” students explore the means by which we can limit light and heat received.

At all grade levels the story is the same, but the lessons chosen explore phenomenology relevant to the specific science standards and benchmarks associated with a grade level. The content and concepts are far broader than MESSENGER science and engineering, as they should be if these educational materials are to be relevant to the curriculum. The MESSENGER story is used simply as one vehicle to address a broad curriculum, which includes an understanding of, e.g., light, heat, shadows, and energy transfer.

Students in grades preK-1 gather experiences that help them to realize that the Sun, an object in the sky, provides the light and heat necessary to warm the land, air and water. Sunlight heats the objects it illuminates; the more light an object is exposed to, the hotter it will get. It is possible to keep an object cooler by protecting it from exposure to light. One way to do this is to put it in the shade. Shadows form if the path of light is blocked by an object; light cannot reach the surface behind the object so that surface remains darker than the brightly lit area around it. By experimenting with objects and their shadows from different light sources, students can gather evidence that light travels in straight lines. As they compare temperatures of objects in full



sunlight or in the shade, they will also discover that shade can protect an object from exposure to light and thus from getting as hot as it would in full sunlight. With this knowledge, students will be able to find ways to keep things cool, just as designers of space missions must.

In grades 2-4, students build on the knowledge that the Sun provides the light and heat to maintain the temperature of the Earth. Light travels in a straight line until it strikes an object. Light can be reflected by a mirror, refracted by a lens or absorbed by the object. Students also begin to understand that phenomena can be observed, measured and controlled in various ways—even the unseen energy produced by the Sun. This process of observing, measuring and controlling is just what scientists do, too. Scientists use many different types of investigations and many different tools depending on the question they are trying to answer. Some tools can help us to distinguish between different forms of the Sun’s energy.

In grades 5-8, students learn about sunlight and other forms of electromagnetic radiation. Since the Sun is hot, it sends much of its energy as visible light. It also sends out other forms of electromagnetic radiation, which we cannot see with our eyes, such as infrared radiation. Infrared radiation is the main form of radiation emitted by cool objects such as planets. In our exploration of the Solar System, we use tools such as visible and infrared light detectors to give us the information we need about the objects we want to study. However, too much light and radiation may cause the instruments, or the spacecraft itself, to heat up or saturate with light. Examination of different solutions to the problem of too much sunlight enables students to understand this concept in a concrete way. The students can then discover ways to protect objects (or ourselves) in a hot environment.

In grades 9-12, students discover the central role sunlight plays in our lives here on Earth. They understand that almost all life on Earth is dependent on the presence of sunlight. Sunlight—and other forms of electromagnetic radiation—is useful for observing the objects in the Solar System, from the Sun itself to other planets and even the tiniest pieces of ice and rock in interplanetary space. But too much light and radiation to which we (or other objects) are exposed can be quite dangerous. By examining simple solutions to staying cool in sunlight, students are able to realize how science can be used to design robust technological solutions to the problem of staying comfortable in a hot environment.



## **A Summary of Lessons in the Unit**

### Grade Level PreK-1 Component

#### ▼ *Lesson: Cooler in the Shadows*

##### - *Shadows*

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

##### - *Bear Shadow*

Students demonstrate their understanding of shadows through a reading of the book *Bear Shadow* by Frank Asch.

##### - *Shadows of the Neighborhood*

In this activity, students will construct a model neighborhood to demonstrate their understanding of shadows. Many questions and suggestions for variants to the activities are presented to allow the teacher to tailor this lesson to particular needs.

##### - *Creating Shadows of 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.

#### ▼ *Design Challenge: What Will Keep My Lunchbox Cool?*

Students often have creative ideas for solving common problems. Their solutions are often limited to ideas rather than to reality and a product. The goal of this activity is to develop the young learner from a creative thinker to a problem solver. In this activity, students will take an everyday problem and design a practical solution. Youngsters will consider how to keep a lunchbox cool during a trip to the beach.

### Grade Level 2-4 Component

#### ▼ *Lesson: Sensing Energy*

Students explore the unseen energy produced by the Sun. Some chemical compounds change color when they absorb the energy of UV light. Students will explore the properties of objects that contain such chemicals (UV beads), specifically, what makes them change color. Students can begin their own investigation to determine the conditions required for the beads to change color or what can prevent the color change.

▼ *Design Challenge: How Do You Prevent Things from Getting Too Hot?*

This challenge provides a motivating experience for children to use a scientific approach, problem solving and cooperative teamwork. They are challenged to work as a team to design and build an effective sunshade for a model of the MESSENGER spacecraft.

Grade Level 5-8 Component

▼ *Lesson: Sensing the Invisible – The Herschel Experiment*

Students reproduce William Herschel’s experiment of 1800 and find out that there is radiation other than visible light arriving from the Sun—in this case, they discover the presence of infrared radiation in sunlight. Students learn that since planets emit most of their light as infrared and not as visible light, infrared is an important tool in studying planets. Students also discuss current uses of infrared radiation and learn that it is both very beneficial and a major concern for the MESSENGER mission to Mercury.

▼ *Lesson: Snow Goggles and Limiting Sunlight*

By studying ancient solutions to the problem of excessive sunlight on human vision, students understand that too much of a good thing can be dangerous! We need some sunlight to see, but too much may be harmful to our eyes. In a similar way, the MESSENGER spacecraft needs some sunlight to operate and observe Mercury, but too much of it can heat up the spacecraft and cause serious damage.

▼ *Lesson: My Angle on Cooling – Effect of Distance and Inclination*

After discussing what heat is and how it travels, students discover that two ways to cool an object in the presence of a heat source are to increase the distance from it or change the angle at which it is faced. The students learn to distinguish which effect is more important for determining the seasons on Earth. They also discuss how the MESSENGER mission to Mercury takes advantage of similar cooling methods to keep the spacecraft comfortable in a high-temperature environment.

▼ *Design Challenge: How to Keep Gelatin from Melting?*

Students will design and build a platform that will be placed on top of a heat source. A 6 cm × 6 cm × 6 cm cube of gelatin will be placed on the platform, with a thermometer inserted in it. The goal is to keep the temperature inside the cube as cool as possible and prevent the gelatin from melting.



### Grade Level 9-12 Component

#### ▼ *Lesson: Star Power! Discovering the Power of Sunlight*

Students estimate the energy output of the Sun using a simple device and discover how much power sunlight provides to Earth. They also estimate what the effect closer to the Sun—at the distance of Mercury—might be. Sunlight and the rest of the electromagnetic spectrum are the main tools with which we study objects in the Solar System.

#### ▼ *Lesson: Dangers of Radiation Exposure*

Radiation can affect living and mechanical things on Earth as well as in space. By estimating their yearly exposure rate to harmful high-energy radiation and cumulative effects over time, students can evaluate the various sources of radiation that are of greatest concern. Since MESSENGER will be subjected to much more intense radiation near Mercury than what a spacecraft near Earth experiences, students also discuss how solar radiation can be an important source of damage and destruction.

#### ▼ *Lesson: Cooling with Sunshades*

After discussing basic properties of temperature and heat, and different ways in which heat can affect substances, students design a simple protective device (sunshade) against excessive sunlight. They also discuss how MESSENGER uses a sunshade to keep comfortable at Mercury's distance from the Sun.

#### ▼ *Design Challenge: How to Keep Items Cool in Boiling Water?*

Students will design and construct a container that will keep items cool when placed in boiling water. A pat of butter will be placed in the container. The goal is to keep the temperature inside the container as cool as possible and prevent the butter from melting.

### **NASA Review of Staying Cool Education Unit**

The Staying Cool Education Unit went through rigorous review by NASA's Science Missions Directorate in 2004. NASA's Office of Space Science's Education Product Review process tasked four educators and three researchers to conduct an intensive peer review of the entire Module. The reviews ranged from 'good' and 'very good' to an 'outstanding' grade given by five of the seven reviewers. The review resulted in NASA incorporating the Staying Cool unit into its 2004 NASA Earth and Space Science Education Workshop at Johnson Space Center.



# STAYING COOL

## CONNECTIONS TO STANDARDS AND BENCHMARKS

This Education Module has been mapped to the National Science Education Standards (National Research Council, National Academy Press, Washington, D.C., 1996), and to the Benchmarks for Science Literacy (American Association for the Advancement of Science, Project 2061, Oxford University Press, New York, 1993). A complete explanation of the Standards can be found at: <http://www.nap.edu/html/nses/html/>. A complete explanation of the Benchmarks can be found at: <http://www.project2061.org/tools/benchol/bolintro.htm>.

	Grades PreK-1		Grades 2-4	
	Cooler in the Shadows	Design Challenge: How Can I Keep My Lunchbox Cool?	Sensing Energy	Design Challenge: How Do You Keep Things from Getting Too Hot?
x - Core standards and benchmarks o - Related standards and benchmarks				
<b>NATIONAL SCIENCE EDUCATION STANDARDS</b>				
<b>SCIENCE AS INQUIRY CONTENT STANDARD A</b>				
Abilities necessary to do scientific inquiry	o		o	o
Understanding about scientific inquiry	o		x	o
<b>PHYSICAL SCIENCE CONTENT STANDARD B</b>				
Light, heat, electricity, and magnetism	x		x	
<b>EARTH AND SPACE SCIENCE CONTENT STANDARD D</b>				
Objects in the sky	x	x	x	
<b>SCIENCE AND TECHNOLOGY CONTENT STANDARD E</b>				
Understanding about science and technology		x		x
Abilities to distinguish between natural objects and objects made by humans				x
<b>SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES CONTENT STANDARD F</b>				
Science and technology in local challenges		o		
<b>AAAS BENCHMARKS FOR SCIENCE LITERACY</b>				
<b>THE NATURE OF TECHNOLOGY BENCHMARK 3</b>				
Design and systems				x
<b>THE PHYSICAL SETTING BENCHMARK 4</b>				
Energy transformations	x			
<b>COMMON THEMES BENCHMARK 11</b>				
Models				x



Grades 5-8

x - Core standards/benchmarks  
o - Related standards/benchmarks

	Sensing the Invisible: The Herschel Experiment	Snow Goggles and Limiting Sunlight	My Angle on Cooling: Effect of Distance and Inclination	Design Challenge: How to keep Gelatin from Melting?
<b>NATIONAL SCIENCE EDUCATION STANDARDS</b>				
<b>SCIENCE AS INQUIRY CONTENT STANDARD A</b>				
Abilities necessary to do scientific inquiry	o	x	o	o
Understanding about scientific inquiry	o	x	o	o
<b>PHYSICAL SCIENCE CONTENT STANDARD B</b>				
Transfer of energy	x		o	
<b>EARTH AND SPACE SCIENCE CONTENT STANDARD D</b>				
Earth in Solar System			x	
<b>SCIENCE AND TECHNOLOGY CONTENT STANDARD E</b>				
Abilities of technological design		o		x
Understanding about science and technology				o
<b>HISTORY AND NATURE OF SCIENCE CONTENT STANDARD G</b>				
Science as a human endeavor	o			
Nature of science	o		o	
History of science	o			
<b>AAAS BENCHMARKS FOR SCIENCE LITERACY</b>				
<b>THE NATURE OF SCIENCE BENCHMARK 1</b>				
Scientific inquiry	o			
<b>THE PHYSICAL SETTING BENCHMARK 4</b>				
Energy transformations				x
Motion	x	x		
<b>THE DESIGNED WORLD BENCHMARK 8</b>				
Health technology				x
<b>COMMON THEMES BENCHMARK 11</b>				
Models		x		
<b>HABITS OF MIND BENCHMARK 12</b>				
Values and attitudes				x
Manipulation and observation	x	x	x	
Critical-response skills				x



Grades 9-12

x - Core standards/benchmarks  
o - Related standards/benchmarks

	Star Power! Discovering the Power of Sunlight	Dangers of Radiation Exposure	Cooling With Sunshades	Design Challenge: How to Keep Items Cool in Boiling Water?
<b>NATIONAL SCIENCE EDUCATION STANDARDS</b>				
<b>SCIENCE AS INQUIRY CONTENT STANDARD A</b>				
Abilities necessary to do scientific inquiry	o	o	o	o
Understanding about scientific inquiry	o	o	o	x
<b>PHYSICAL SCIENCE CONTENT STANDARD B</b>				
Conservation of energy and increase in disorder	o		x	
Interactions of energy and matter	x			
<b>EARTH AND SPACE SCIENCE CONTENT STANDARD D</b>				
Energy in the Earth system	x			
<b>SCIENCE AND TECHNOLOGY CONTENT STANDARD E</b>				
Abilities of technological design			o	x
<b>SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES CONTENT STANDARD F</b>				
Nature and human-induced hazards		x		
Science and technology in local, national, and global challenges			o	
<b>AAAS BENCHMARKS FOR SCIENCE LITERACY</b>				
<b>THE NATURE OF SCIENCE BENCHMARK 1</b>				
Scientific inquiry				x
The scientific enterprise		x		
<b>THE PHYSICAL SETTING BENCHMARK 4</b>				
Energy transformations	x		x	
<b>THE DESIGNED WORLD BENCHMARK 8</b>				
Materials and manufacturing			x	
<b>HISTORICAL PERSPECTIVES BENCHMARK 10</b>				
Splitting the atom		x		
<b>HABITS OF MIND BENCHMARK 12</b>				
Values and attitudes				x



