National Aeronautics and Space Administration

NASA eClips™

Educator Guide

NASA LAUNCHPAD:

Cooling Off

Educational Product	
Educators & Students	Grades 9-12

NP-2008-09-107-LaRC

www.nasa.gov

Cooling Off

Grade Level: 9-12

Subjects:

Chemistry
Physics
Physical Science

Teacher Preparation Time:

1 hour

Lesson Duration:

Five 55-minute class meetings

Time Management:

Class time can be reduced to three 55-minute time blocks if some work is completed at home.

National Standards

National Science Education Standards (NSES)

- Science as Inquiry
- Physical Science
- Science and Technology

National Council of Teachers of Mathematics (NCTM)

- Measurement
- Data Analysis and Probability
- Representation

International Society for Technology in Education: National Educational Technology Standards (ISTE/NETS)

- Critical Thinking, Problem Solving, and Decision Making

Lesson Overview

Students are introduced to challenges of maintaining temperatures while living in space. Thinking and acting like scientists and engineers, students experiment to learn how to measure the specific heat capacity (or simply, specific heat) of water and then design an improved cooling system like those used in spacesuits.

This lesson is developed using a 5E model of learning. This model is based upon constructivism, a philosophical framework or theory of learning that helps students connect new knowledge to prior experience. In the ENGAGE section of the lesson, students look at NASA technology and its relationship to improvements in athletic clothing and equipment. They learn about technology in spacesuit design and the use of this technology in everyday life. Working in teams, students conduct experiments relating to specific heat capacity on a cooling system they design in the EXPLORE and EXPLAIN sections. They are challenged to improve the cooling system in the EXTEND section of this lesson.

Students assess their understanding and abilities throughout the lesson and revisit the Essential Questions during the EVALUATE section.

Icons flag five areas of interest or opportunities for teachers.

- TECHNOLOGY highlights opportunities to use technology to enhance the lesson.
- MODIFICATION denotes opportunities to differentiate the lesson.
- RESOURCES relates this lesson to other NASA educator resources that may supplement or extend the lesson.
- CONNECTIONS identifies opportunities to relate the lesson to historical references and other topics or disciplines.
- CHECKING FOR UNDERSTANDING suggests quick, formative assessment opportunities.

Enduring Understandings

These *Project 2061 Benchmarks for Science Literacy* guide teachers as they work to improve science literacy for all students.

- Investigations are conducted for different reasons, including: to explore new phenomena; to check on previous results; to test how well a theory predicts; and to compare theories.
- Engineers use knowledge of science and technology, together with strategies of design, to solve practical problems. Scientific knowledge provides a means of estimating what the behavior of things will be even before they [observations] are made. Moreover, science often suggests new kinds of behavior that had not even been imagined before, and so leads to new technologies.
- Although the various forms of energy appear very different, each can be measured in a way that makes it possible to keep track of how much of one form is converted into another. Whenever the amount of energy in one place diminishes the amount in other places or forms increases by the same amount.

Essential Questions

- What factors determine the relationship between the amount of heat absorbed by an object and the temperature change of that object?
- How is the challenge of returning people to the Moon driving scientific and technological advancement?

Instructional Objectives:

Students will
- recognize the challenges to living in places other than Earth;
- increase their understanding of the considerations involved in the design of spacesuits for astronauts;
- experiment to observe how heat can be collected, stored, absorbed, and dissipated;
- use a formula to calculate the specific heat capacity of water;
- use the design process to create and improve a cooling system; and
- document the design process using instructional technology.

NASA Background:

NASA's blueprints for an outpost on the Moon are shaping up. The agency's Lunar Architecture Team has been hard at work, looking at concepts for habitation, rovers, and spacesuits. NASA plans to return astronauts to the Moon by 2020, using the Ares and Orion spacecraft already under development.

Astronauts will set up a lunar outpost – possibly near a south pole site called Shackleton Crater – where they will conduct scientific research, as well as test technologies and techniques for possible exploration of Mars and other destinations.

Even though Shackleton Crater entices NASA scientists and engineers, they don't want to limit their options. To provide for maximum flexibility, NASA is designing hardware that would work at any number of sites on the Moon.

First, astronauts on the Moon will need someplace to live. NASA officials had been looking at having future Moonwalkers bring smaller elements to the Moon and assemble them on site. But the Lunar Architecture Team found that sending larger modules ahead of time on a cargo lander would help the outpost get up and running more quickly. The team is also discussing the possibility of a mobile habitat module that would allow one module of the outpost to relocate to other lunar destinations as mission needs dictate.

Figure 1: Concept of one potential design for a future lunar rover. Spacesuits would be attached to the exterior of the rover. ***Image Credit:*** *NASA*

NASA is also considering small, pressurized rovers that could be key to productive operations on the Moon's surface (Figures 1 and 2). Engineers envision rovers that would travel in pairs – two astronauts in each rover – which could be driven nearly 200 kilometers (about 125 miles) away from the outpost to conduct scienctific investigations or other activities. If one rover had mechanical problems, the astronauts could ride home in the other.

Astronauts inside the rovers wouldn't need special clothing because the pressurized rovers would have what's called a "shirt-sleeve environment." Spacesuits would be attached to the exterior of the rover. NASA's lunar architects are calling them "step in" spacesuits because astronauts could crawl directly from the rovers into the suits to begin a Moonwalk.

Figure 2: Concept of one potential design for a future lunar rover. Spacesuits would be attached to the exterior of the rover. ***Image Credit:*** *NASA*

Astronauts out on extravehicular activity are in a constant state of exertion. Body heat released from this exertion can quickly build up inside a spacesuit, leading to heat exhaustion. Body heat is controlled by a liquid-cooled garment made from stretchable spandex fabric and laced with small diameter plastic tubes that carry chilled water. The water is circulated around the body. Excess body heat is absorbed into the water and carried to the suit's backpack where it flows beside a porous metal plate that permits some of the heat to escape into outer space. The water instantly freezes on the outside of the plate and seals the pores. More water circulates along the back of the plate. Heat in the water is conducted through the metal to change the ice into water vapor.

In the process, the circulating water is chilled. The process of freezing and thawing continues constantly at a rate determined by the heat output of the astronaut.

Sources: NASA Website:
http://www.nasa.gov/mission_pages/exploration/mmb/lunar_architecture.html

For more information, visit the Exploration Systems Mission Directorate homepage
http://www.nasa.gov/directorates/esmd/home/index.html

5E Inquiry Lesson Development
ENGAGE (20 to 30 minutes)

1. Organize students into groups of two or three to brainstorm answers to this question: How has athletic clothing and equipment changed and improved? What discoveries or research led to these changes? *(Some examples might be cloth that wicks away moisture, more absorbent materials for sports shoes, materials that increase performance, and athletic equipment. Some of these changes are due to technology transfer and spinoffs as a result of NASA technology.)*
   TECHNOLOGY Your students may research this topic to increase their understanding and learn more about NASA technology transfer and spinoffs at the NASA Spinoff Homepage, ***http://www.sti.nasa.gov/tto/***
   RESOURCES Students can also read more about NASA spinoffs found in clothing in the article *What Can I Wear Today?* found at ***http://www.nasa.gov/audience/foreducators/5-8/features/F_What_Can_I_Wear.html***
2. Poll the student groups and list the items they've identified, reinforcing open brainstorming rules *(all ideas are acceptable)*. As a class, discuss how these improvements increase performance. Which of these improvements relate to cooling or heating an athlete? *(Materials may wick away moisture to cool and heat athletes, new materials that are lightweight insulators, etc.)*
3. In addition to use by athletes, these special materials are used to heat, cool, and protect astronauts while in space.
   TECHNOLOGY To find out more about spacesuits, show the NASA video segment *Spacesuits and How They Work (5:17)* found at the NASA Portal:
   http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Spacesuits_and_How_They_Work.html
4. Once students have viewed the video segment, ask them to answer these questions:
   a. Why do astronauts need spacesuits?*(Protection from low pressure, body temperature regulation, protection from impacts with space debris)*
   b. Describe the construction of a spacesuit.*(Urethane coated nylon for pressurization, polyester layer to give structure, 5 layers of aluminized mylar for thermal protection, Nomex/Teflon/Kevlar layer to keep from tearing, control pack, life support pack, long underwear with tubes for water to flow through to keep astronauts from overheating)*
5. Lead a whole-class discussion about the similarities and differences between the items the students listed and spacesuits. *(Discussion will vary based on clothing items students identified.)*
6. CONNECTIONS Since the first spacesuits in the 1960's, spacesuits have changed and evolved as engineers have developed new resources. The spacesuits have also been used for purposes other than space travel. Share some innovative ideas with students through these materials:
   - NASA article, *NASA "Spacesuits" Help Brothers With Rare Genetic Defect*
     http://www.nasa.gov/centers/johnson/news/releases/1996_1998/j97-30.html
   - NASA eClips video segment, *The Making of the Biosuit (7:02)*.
     This segment may be found at NASA eClipsYou Tube™
     http://www.youtube.com/watch?v=GoS4Lzr4dhE&feature=PlayList&p=D7BEC5371B22BDD9&index=1
   - NASA eClips video segment, *Protective Materials for Spacecraft (6:27)*. This segment may be found at NASA eClips You Tube™
     http://www.youtube.com/watch?v=H6EL9kdzaXw&feature=PlayList&p=D7BEC5371B22BDD9&index=2
   - NASA multimedia gallery, *Evolution of the NASA Spacesuit*
     http://www.nasa.gov/multimedia/mmgallery/features_archive_1.html

EXPLORE (30 to 40 minutes)

Different materials require different amounts of heat to produce similar changes in their temperatures. In other words, materials have different specific heat capacities. The **specific heat capacity** of a material is the **amount of energy it takes to raise the temperature of 1 gram of the material 1 degree Celsius**. Specific heat capacity can be measured in joules per gram per degree Celsius (J/g ˚C).

Specific heat gives us an indication of how quickly a substance will heat up. Metals, which have low specific heat capacity values, warm up much more quickly than water, which has a high specific heat capacity. That is why a pot on a stove heats up more quickly than the water inside the pot. During this EXPLORE activity students will investigate the cooling capabilities of water using an experimental setup that mimics the cooling system used in a spacesuit.

1. Organize students into teams of two or three. Provide each team with these materials:
   - two 1-pound or standard size coffee cans with plastic lids
   - 4 meters of aquarium tubing
   - two buckets
   - two long red liquid or digital laboratory thermometers
   - duct tape
   - ice
   - water
   - heat lamp (≥100 watts)
   - single-hole punch
   - large nail and hammer
   - Student Handouts
   - optional: digital camera, graphing calculators, and temperature probes, drill, or metal punch
2. Have students review the procedure in the Student Handout (page 15), highlighting all safety concerns.
3. TECHNOLOGY If available, use probeware to collect the temperature data. Texas Instruments, Vernier, and Casio graphing calculators/temperature probe systems with capabilities to record data. Graphing calculators or computer programs may be used to display data.
4. MODIFICATION Some management tips for this experiment:
   a. To save time you may wish to assemble the coffee can and aquarium tubing ahead of time.
   b. Holes in the cans may be made for the students using a metal punch or drill.
   c. Be sure that students hold the bucket of ice water above the level of the coffee can.
   d. There are several options students can use to start suction. These include: CPR mouth barriers, pipet pumps, turkey basters, irrigation bulbs for ears/nose. Explain the safety and experimental reasons for not using one's mouth directly.
5. CONNECTIONS This activity can be connected to the topics of molecular structure, energy transfer, and intermolecular forces by explaining the high heat capacity of water.

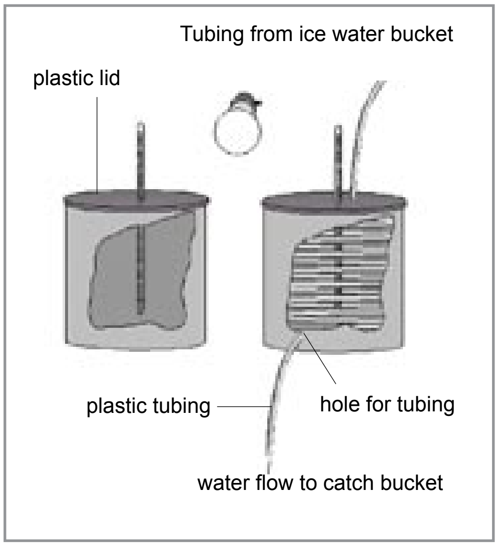

Figure 1: Tubing from ice water bucket

EXPLAIN (30 to 40 minutes)

During the EXPLORE activity students observed how water can absorb heat from the surroundings and thereby lower the temperature of the surroundings.

MODIFICATION Class time may be reduced by assigning calculations and questions as homework.

1. Discuss the data. These questions guide discussion and are included in the Student Handout:
   a. How did the temperature inside each can compare before cooling (Table 1) and after cooling (Table 2)? *(Before cooling, the temperatures are about the same. After cooling, the temperature inside the water-cooled can should be lower. Students may also want to record the temperature of the water before it is added to the tubes and the temperature of the water after it has been used to cool the can. Look for a pattern in the two sets of data.)*

b. Ask students to create a graph of temperature (*y*-axis) vs. time (*x*-axis) for the data they collected. They should graph both sets of data on the same graph using labeled solid and dashed lines (or distinct colors) to distinguish between the empty can and the can with the tubing.

TECHNOLOGY Students could use spreadsheet software or graphing calculators to create the graphs.

c. CHECKING FOR UNDERSTANDING Explain the results you observed and reported in question a. above. *(Students may develop several explanations. Guide students to understand that the water circulating through the can is the cause for heat transfer, thus creating the difference in temperature between the two cans. Heat is the transfer of thermal energy between two bodies that are at different temperatures so heat flows from a hot object to a colder one with the first releasing energy and the second absorbing it. As the temperature of the water-cooled can decreases, the temperature of the water inside the tubes increases, demonstating this exchange of energy.)*

d. Thermal energy is the energy of the movement of the molecules of a substance. The gas phase of a substance has a higher thermal energy (more molecular movement) than the liquid phase. Liquids have more rapidly moving molecules than their solid phases.

Heat is the flow of energy from one substance to another. Heat energy moves from a source of higher energy to a source of lower energy, spontaneously flowing from one substance to another until the two temperatures are equal. The symbol for heat is *q*. Heat is measured in joules (J) in the International System of Units (SI).

2. CONNECTIONS SI comes from the French expression ***Le Système International d'Unités***, or the International System of Units, the system of measurements and units agreed upon by scientists around the world for doing scientific studies and calculations so that scientists could clearly understand other scientists' data and experimental results. Sometimes SI units are the same as metric system units and sometimes they are different.
Calorie is a common unit of heat energy. There are 1000 calories of heat energy in a U.S. food label Calorie (noted with a capital C). Each Calorie is equivalent to 4,184 joules.

3. Specific heat or specific heat capacity (*c*) of a substance is the energy needed to raise the temperature of one gram of a substance by one degree Celcius. Water (in its liquid form) has a relatively high heat capacity (*c*) of 4.184 J/g°C, making water an effective coolant. Metals have a significantly lower heat capacity than water. It takes more energy to raise the temperature of water than it does to raise the temperature of the same mass of metal.

a. Heat (*q*) can be measured using the formula: mass x specific heat x change in temperature, or

$$q = m\,c\,\Delta T$$

where:

q = heat in joules (J)
m = mass in grams (g)
c = specific heat capacity in joules per gram per degree Celsius (J/g °C)
Δ T = change in temperature in degrees Celsius (final temperature – initial temperature)
(Greek letter Δ is pronounced "delta" and means change in.)

b. Students can calculate the amount of heat absorbed by the air in each coffee can. The specific heat of air is about 1.00 J/g ˚C.

To calculate the mass of air in the can, calculate the volume of the coffee can in cubic centimeters ($V_{cylinder} = \pi r^2 h$) and then multiply by the density of air (d_{air} = 1.239 mg/cm^3).

All values given assume measurements at 20˚C and 1 atm pressure.

Example calculations for a coffee can with a height of 13.5 cm and a diameter of 9.8 cm that experienced a change in temperature of 8.5˚C: (Radius of can is calculated by dividing the diameter by 2 because students will be unable to measure the radius directly.)

π	=	3.14
r	=	radius
h	=	height

- Volume of air = $\pi(4.9\ cm)^2(13.5\ cm) = 1100\ cm^3$
- Mass of air = $(1100\ cm^3)\ (1.239\ cm^3) = 1400$ mg or 1.4 g
- Amount of heat released = (1.4 g) (1.00J/g ˚C) (8.5 ˚C) = 12 J

c. CONNECTIONS This activity can be connected to the topic of Gas Laws by asking students to calculate the volume the gas would occupy at Standard Temperature and Pressure (STP).

d. MODIFICATION You can calculate the mass of air ahead of time and provide the value to students. You can also ask students to describe how they would calculate the mass of air if given only the density of air.

MODIFICATION As an additional modification challenge students to calculate the volume of the tubing within the water-cooled can to determine whether the tubing's volume significantly impacts the mass of air contained in the can which, in turn, would impact the amount of heat absorbed by the air in the can.

4. Use these questions to discuss and summarize the design of this activity. These questions are found in the Student Handout. *(Students' answers will vary.)*
   a. How can the flow of icy water be controlled? *(Answers will vary, but may include: add a clamp or change the size of the tubing.)*
   b. Suggest a way to maintain a constant temperature inside the can with the tubing. *(Answers will vary, but may include: add insulation.)*
   c. What would happen if you moved the light source closer to the can? What real world problem might this simulate? *(Temperatures will increase. Answers to real world problems will vary, but may include: astronauts leave the shade of their spacecraft or the International Space Station and are exposed to the intense heat of the sun.)*
   d. Explain how a liquid cooling garment could be constructed that could operate continuously without siphons and buckets of ice water that eventually run out. Relate your answer to what you learned about spacesuit design in the NASA video segment. *(Answers will vary, but may include: use a closed-loop system with a pump; designers could take advantage of the cold temperatures of space by having a portion of the cooling system be a bit less insulated so the outside temperatures will cool water passing through it; if astronauts are working in the shade, or space "night", the outside of the suit will be cooler; if astronauts move out of the shade, they will have to deal with heat from the sun.)*

5. CHECKING FOR UNDERSTANDING Ask students to revisit the first Essential Question and write a paragraph organizing their learning from this lesson.

   What factors determine the relationship between the amount of heat absorbed by an object and the temperature change of that object? *(This relationship is determined by the specific heat of the substance and its mass. The higher the specific heat capacity of a substance, the smaller its temperature change for a given amount of heat. Also, the larger the mass of the substance, the smaller the temperature change per quantity of heat transferred. Mathematically speaking, the temperature change is inversely proportional to mass and specific heat capacity. Temperature gradients drive heat flow. Heat is the energy that flows between two objects because of a difference in temperature. Heat will flow from the warm to cold until the temperature gradient no longer exists. In this experiment, however, a temperature gradient will exist as long as the light is emitting heat and cold water is flowing through the tube.)*

EXTEND (two 55-minute class meetings)

MODIFICATION Class time may be reduced by assigning parts of the design process as homework.

There are many considerations in the design process. During this challenge, students will think and act like engineers as they redesign the cooling system used in the EXPLORE section to maximize cooling while minimizing water consumption and cost.

1. To complete the Challenge, students will be organized into Design and Engineering teams.
   RESOURCES Find out more about how to organize these teams and the design process from *NASA's Lunar Nautics Educator Guide*, ***http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Lunar_Nautics_Designing_a_Mission.html***. This guide contains activities that lead to designing a mission to live and work on the Moon. Pages 118 – 119 offer tips for forming and implementing design teams.
2. Use the design sheets and design project rubric to help students work through the design process.
   TECHNOLOGY Encourage the students to document the process with digital images.
3. Students construct a redesigned cooling system with the following goals:
   a) The air in the redesigned can should be at least as cool as the original.
   b) The redesigned cooling system should use as little water as possible.
   c) The redesigned cooling system should be economical in the use of materials.
4. Suggested materials for the redesign project:
   a) Various diameters and types of tubing
   b) Various types of tapes and other adhesives
   c) Small C clamps
   d) Other readily available materials the students might suggest
5. Each material should be assigned a cost. In the case of tubing, tape, etc. the price should be per unit length.
6. Follow the procedure in the EXPLORE section to test and gather data. In addition to temperature data, students should measure the amount of water in the collection bucket at the end of 10 minutes.
7. To evaluate the overall efficiency of the design, use the following "formula" to rate the design:

$$\textbf{Score} = \frac{\textbf{[(change in temperature using initial design) – (change in temperature using redesign) + 1000]}}{\textbf{(total cost of materials + amount of water used in liters)}}$$

   Students are asked to divide the difference in air temperatures between the initial design and redesign by the cost of materials and the amount of water to quantify the most efficient use of materials. Similar to a spacesuit, the point of this cooling system is to maintain a constant temperature. A more efficient system will reduce the change in temperature (e.g., the air temperature will not be significantly affected by the heat from the light). For example, if room temperature is 23°C, and the temperature increased to 35°C with the initial design, the change in temperature will be 12°C. With the improved cooling system, the air temperature might only increase to 30°C, creating a change of 7°C.

   Note that the higher the score the better the efficiency of the design.

8. Students will present their model and summarize its design process.
   TECHNOLOGY Students may create a multimedia presentation of their cooling system and its design.

EVALUATE (30 to 40 minutes)

These activities may be used to evaluate your students' understanding.

MODIFICATION Class time may be reduced by assigning sections to be completed as homework.

1. Scientists observe, predict, measure, test, and discover the workings of the natural world. Engineers extend an understanding of the natural world to design, build, and test innovations for the designed world. Mathematicians use numbers to help quantify and make predictions within the natural and designed worlds. **Ask students to reflect on times throughout this lesson when they are thinking and acting like engineers, mathematicians, and scientists.**

2. Use questions, discussions, and student handouts in the lesson to assess students' understanding.

3. Use the design sheets and the grading rubric to evaluate the performance of the students during the EXTEND challenge.

4. Ask students to summarize their learning by answering these journal questions:

   a. Compare the skills needed during the EXPLORE and EXTEND activities. When were you thinking more like engineers than scientists? *(Answers vary)*

   b. Evaluate the experimental design of your EXPLORE experiment using these questions.

      1. What were the independent and dependent variables in this activity? *(types of materials used to modify the cooling system is the independent variable; how much the temperature changes inside the can is the dependent variable)*

      2. What were some sources of error for this experiment? *(distance from light to cans not the same, different types of cans used for cooled and non-cooled cans, no ice in the ice water supply)*

      3. How could you improve the accuracy of this experiment? *(make a stand so that light and cans are fixed, place set up in a closed system so no heat is absorbed from surroundings)*

      4. How is the challenge of returning people to the Moon driving scientific and technological advancement? *(Answers vary)*

PROBLEM, CONSTRAINTS, AND BRAINSTORMING STEP 1STEP 2STEP 3

Cooling Off
Design Sheet B

IDEAS, POSSIBILITIES, AND DESIGN CHOICE

Select two or three optimal ideas from the brainstormed list on Design Sheet A. Make a detailed sketch of each design. Select one design to construct. List reasons for your choice. Sketches should be labeled with dimensions and materials for each part.

STEP 4

Generate Ideas

STEP 5

Explore Possibilities - Sketches

STEP 6

Select a Design; Justify your Choice

MODEL OR PROTOTYPE

List the materials used to construct your selected model from Design Sheet B, or redesign of an existing model, and write a detailed procedure for its construction. You may continue the procedure on additional paper if needed.

STEP 7

Build a Model or Prototype - Materials and Procedure

REFINE THE DESIGN

STEP 8
Testing

Hypothesize about your cooling apparatus' performance during the test. Strive to use an If.., then...format.
For example, "If the redesigned model has increased in size (change in the independent variable), then the temperature change will be greater (change seen in the depended variable)."

Total cost of your design: ___________

Results of testing before and after the redesign:

Amount of change from the original: _____________

Calculated Efficiency score:

Evaluation
List the strengths and weaknesses of your apparatus' design here or on a separate sheet.

Redesign
If you were to build this apparatus again, what would you do differently and why?

Group Members: ____

____

Rubric Category	Score
Identify the Problem, Constraints, and Brainstorming • The problem is identified and explained in detail. • All criteria and constraints are listed and clarified. • Possible solutions are listed following brainstorming session. • Evaluation criteria/predictions are closely connected to the problem.	
Generate Ideas, Possibilities, and Design Choice • Two or three ideas are selected from brainstormed list. • Detailed sketches are created for selected ideas. • Sketches are labeled with dimensions and materials for each part. • One design is selected to construct with reasons for your choice.	
Build the Model or Prototype • Detailed list of materials is included. • Detailed procedures are included and followed. • Scale and details mimic the original design. • Data tables are complete and well organized. • Materials handled and stored appropriately. • Safety rules are followed.	
Refine the Design • Hypothesis following an “if.., then…” format is developed for the design. • Strengths and weaknesses of the design are listed. • Modifications to improve the design are documented. • Reflections show great insight and understanding of process and goals of project.	
Evaluate Performance • Model or prototype performs with intended results. • Results are repeated in additional trials.	
Present Findings • Presentation is very well-organized. • Presentation covers all areas of the design process. • Presentation is clearly communicated (verbally or visually) • Presentation includes contributions from all team members.	
TOTAL (out of 24 pts possible)	

4 (Excellent) = All criteria (procedures, steps, and details) are met or followed.
3 (Good) = Most criteria are met with only a few mistakes.
2 (Fair) = Many criteria are not met and/or there are many mistakes.
1 (Poor) = Most criteria are not met.
0 (No effort) = No effort to meet criteria.

ESSENTIAL QUESTIONS

- What factors determine the relationship between the amount of heat absorbed by an object and the temperature change of that object?
- How is the challenge of returning people to the Moon driving scientific and technological advancement?

BACKGROUND

NASA plans to return astronauts to the Moon by 2020, using the Ares and Orion spacecraft already under development. Astronauts will set up a lunar outpost where they will conduct scientific research, as well as test technologies and techniques for possible exploration of Mars and other destinations. To provide for maximum flexibility, NASA is designing small, pressurized rovers that could be key to productive operations on the Moon's surface (Figures 1 and 2).

Figure 1: Concept of one potential design for a future lunar rover. Spacesuits would be attached to the exterior of the rover. ***Image Credit:*** *NASA*

Engineers envision rovers that would travel in pairs – two astronauts in each rover – which could be driven nearly 200 kilometers (about 125 miles) away from the outpost to conduct scientific experiments or other activities. Astronauts inside the rovers wouldn't need special clothing because the pressurized rovers would have what's called a "shirt-sleeve environment." Spacesuits would be attached to the exterior of the rover. NASA's lunar architects are calling them "step in" spacesuits because astronauts could crawl directly from the rovers into the suits to begin a Moonwalk.

Figure 2: Concept of one potential design for a future lunar rover. Spacesuits would be attached to the exterior of the rover. ***Image Credit:*** *NASA*

Astronauts out on extravehicular activity are in a constant state of exertion. Body heat released from this exertion can quickly build up inside a spacesuit, leading to heat exhaustion.

Body heat is controlled by a liquid-cooled garment made from stretchable spandex fabric and laced with small diameter plastic tubes that carry chilled water. The water is circulated around the body. Excess body heat is absorbed into the water and carried to the suit's backpack where it flows beside a porous metal plate that permits some of the heat to escape into outer space. The water instantly freezes on the outside of the plate and seals the pores. More water circulates along the back of the plate. Heat in the water is conducted through the metal to change the ice into water vapor. In the process, the circulating water is chilled. The process of freezing and thawing continues constantly at a rate determined by the heat output of the astronaut.

Sources: NASA Website:
http://www.nasa.gov/mission_pages/exploration/mmb/lunar_architecture.html and NASAexplores:
http://media.nasaexplores.com/lessons/01-038/9-12_1.pdf

For more information, visit the Exploration Systems Mission Directorate homepage
http://www.nasa.gov/directorates/esmd/home/index.html

Vocabulary

constraint - Any limit or restriction given for the design process is called a *constraint*.

criteria - *Criteria* are specifications or rules guiding the design process, such as size, type of material, or dollar limit to build the model.

design process - The *design process* is a series of steps in designing and refining/improving something. (See Figure 3.)

Steps of the Design Process

1. Identify the problem
2. Identify criteria and constraints
3. Brainstorm possible solutions
4. Generate ideas
5. Explore possibilities
6. Select a design
7. Build a model or prototype
8. Refine the design, repeating steps 1-8

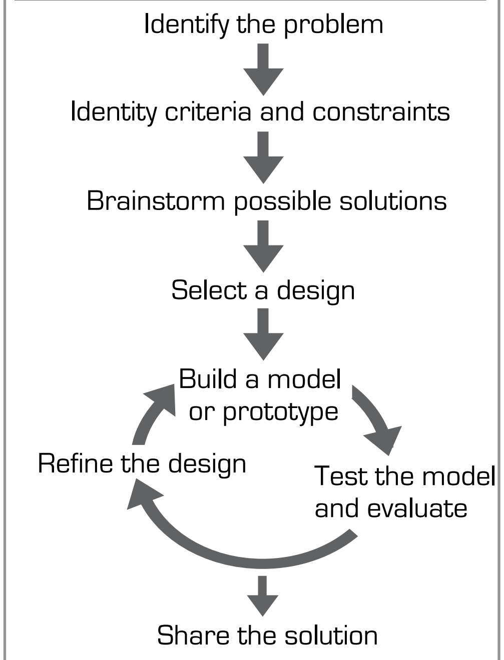

Figure 3: Steps of the Design Process

density - The *density* (*d*) of a material or object is a measure of how tightly the matter within it is packed together, and is given by the ratio of its mass (*m*) to its volume (*V*), or $d = m/V$. It is typically expressed in kilograms per cubic meter (kg/m^3) or grams per cubic centimeter (g/cm^3) or grams per milliliter (g/mL).

energy - *(see also thermal energy) Energy* is the ability to do work, and there are several different forms of energy (e.g., kinetic, potential, thermal, sound, light, chemical, etc.). While energy may be transformed from one form to an other, the total energy remains the same within a closed system.

heat - *Heat* is the amount of thermal energy absorbed, released, or transferred by a material. This is typically expressed as *q*, and is measured in joules (*J*).

mass - The amount of matter in an object is the object's *mass*. Objects are made up of atoms containing varying numbers of protons, neutrons, and electrons which determine their mass. Mass is also described as how hard it is to change the motion of an object.

matter - *Matter* is often defined as anything that has mass and takes up space (has volume), and it is the generic term for the substance of which all physical objects are composed. Matter can be in several different states, including solids, liquids or gases.

model - A *model* represents something else. A model might be a drawing or a 3-D object. Models are smaller than the original object or made out of less expensive materials than the actual object. Many iterations (repetitions or versions) of models are often needed. The first is often a drawing scaled down to fit on a piece of paper. The next may be a series of structures made out of paper, cardboard, plastic, or other readily available materials.

prototype - A *prototype* is an original or model on which something is based.

simulation - A *simulation* is something that substitutes for the real thing. For instance, flight simulators are mockups for pilots to practice so they do not crash real aircraft under different weather and equipment emergencies. A simulation can have many qualities of the authentic experience without all the expenses and dangers. A model simulates - or is a simulation of - a real object or event.

specific heat - Different materials require different amounts of heat to produce similar changes in their temperatures. In other words, materials have different specific heat capacities, often called, *specific heat*. The specific heat capacity of a material is the amount of energy it takes to raise the temperature of 1 gram of the material 1 degree Celsius. Specific heat capacity can be measured in joules per gram per degree Celsius (J/g ˚C).

thermal energy - *Thermal energy* is the energy of movement of the molecules within a substance. The higher the temperature, the faster the molecules move, thus temperature can be used as a measure of thermal energy.

volume - The *volume* of an object is how much space it occupies, and it is typically expressed in milliliters (mL), cubic centimeters (cm or cc), liters (L) or cubic meters (m^3).

A. EXPLORE

Materials

- two 1-pound or standard size coffee cans with plastic lids
- 4 meters of aquarium tubing
- two buckets
- two long red liquid or digital laboratory thermometers
- duct tape
- ice
- water
- heat lamp
- single-hole punch
- large nail and hammer
- flood light and fixture
- optional: digital camera
- optional: graphing calculator, temperature probes

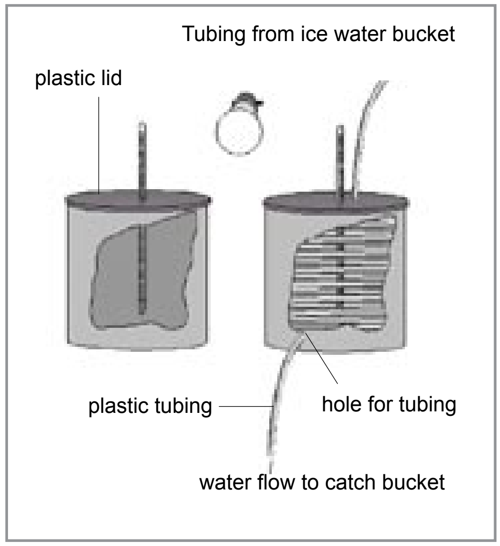

Figure 1: Tubing from ice water bucket

PROCEDURE

1. Punch a hole near the bottom of the side of a metal coffee can using a large nail and a hammer. The hole should be large enough to pass aquarium tubing through. Be sure to follow SAFETY procedures throughout the process. (GOGGLES REQUIRED.)
2. Punch a hole in the plastic lid of the can so that tubing can pass through it.
3. Punch another hole in the center of the lid so that a thermometer will fit snugly into it.
4. Finally, punch a hole in the center of the second coffee can lid for another thermometer.
5. Loosely coil the aquarium tubing, and place it inside the first coffee can. Use bits of tape to hold the coils to the walls and to keep them spread out evenly. Pass the lower end of the tube through the hole in the can wall and the upper end through the outer hole in the lid. The lower end of the tube should extend to the catch bucket that will be placed below the can. The upper end will have to reach to the bottom of the ice water bucket. That bucket will be elevated above the can.
6. Insert a thermometer into each can. The thermometer bulb should be positioned about 4 cm above the bottom of the can.
7. Place the two cans on a tabletop. Direct the light from the heat lamp to fall equally on the two cans. The light should be no more than about 25 centimeters away from the cans.
8. Fill a bucket with ice water and elevate it above the two cans. You can color the water with food coloring to increase its visibility in the tubing.
9. Place the catch bucket below the two cans.
10. Turn on the light. Observe and record the temperatures on the two thermometers in Table 1. After 2 minutes, again observe and record the temperatures in Table 1.
11. Place the upper end of the aquarium tubing into the ice water and use suction to start the flow of water. Let the water drain into the catch bucket.
12. Observe and record the temperature of the two cans at 30-second intervals for 10 minutes in Table 2.

Table 1. Temperature Baseline

	Can without tubing		Can with tubing
Initial Temperature (˚C)			
Temperature after 2 minutes (˚C)			

Table 2. Temperature Data

Time (minutes: seconds)	Temperature (˚C)		Time (minutes: seconds)	Temperature (˚C)	
	No Tubing	Tubing		No Tubing	Tubing
0:00			5:30		
0:30			6:00		
1:30			6:30		
2:00			7:00		
2:30			7:30		
3:00			8:00		
3:30			8:30		
4:00			9:00		
4:30			9:30		
5:00			10:00		

B. EXPLAIN

1. Examine the data. How did the temperature inside of each can compare before cooling (Table 1) and after cooling (Table 2)?

2. Create a graph of temperature (*y*-axis) vs. time (*x*-axis) from the data in Table 2. Graph both sets of data on the same graph using labeled dashed line and solid lines (or different colors) to distinguish between the can with no tubing and the can with the tubing.

3. Examine the graph and compare the trends in temperature for the two cans. Explain the results you observed and recorded.

4. Heat (q) can be measured using the formula: mass x specific heat x change in temperature, or

$$q = m\,c\,\Delta T$$

where:

q = heat in joules (J)

m = mass in grams (g)

c = specific heat capacity in joules per gram per degree Celsius (°C)

ΔT = change in temperature in degrees Celsius (final temperature – initial temperature)
(Greek letter Δ is pronounced “delta” and means change in.)

a. Calculate the volume of each can. Assume the cans are perfect cylinders.

b. The density of air is 1.239 mg/cm^3. Use this information and your answer to (a) to calculate the mass of air in each can.

c. The specific heat of air is about 1.00 J/g ˚C. Calculate the amount of heat absorbed by the air in each of the cans.

d. How much heat was released by the air in the can with the tubing?

5. Analyze the design of this experiment by answering the following questions:
   a. How can the flow of icy water be controlled?

   b. Suggest a way to maintain a constant temperature inside the can with the tubing.

   c. What would happen if you moved the light source closer to the can? What real world problem might this simulate?

   d. Explain how a liquid cooling garment could be constructed that could operate continuously without tubing and buckets of ice water that eventually run out.

B. EXPLAIN

1. Examine the data. How did the temperature inside of each can compare before cooling (Table 1) and after cooling (Table 2)?
   (Before cooling, the temperatures are about the same. After cooling, the temperature inside the water-cooled can should be lower. Students may also want to record the temperature of the water before it is added to the tubes and the temperature of the water after it has been used to cool the can. Look for a pattern in the two sets of data.)

2. Create a graph of temperature (*y*-axis) vs. time (*x*-axis) from the data in Table 2. Graph both sets of data on the same graph using labeled dashed line and solid lines (or different colors) to distinguish between the can with no tubing and the can with the tubing. *(Answers will vary.)*

3. Examine the graph and compare the trends in temperature for the two cans. Explain the results you observed and recorded.
   (Students may develop several explanations. Guide students to understand that the temperature gradient between the air and the water circulating through the can is the cause for heat transfer. Heat is the transfer of thermal energy between two bodies that are at different temperatures so heat flows from a hot object to a colder one with the first releasing energy and the second absorbing it. As the temperature of the water-cooled can decreases, the temperature of the water inside the tubes increases, demonstrating this exchange of energy.)

4. Heat (*q*) can be measured using the formula: mass x specific heat x change in temperature, or

$$q = m\,c\,\Delta T$$

where:

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a. Calculate the volume of each can. Assume the cans are perfect cylinders.
(Answers will vary.)

b. The density of air is 1.239 mg/cm^3. Use this information and your answer to (a) to calculate the mass of air in each can.
(Answers will vary.)

c. The specific heat of air is about 1.00 J/g ˚C. Calculate the amount of heat absorbed by the air in each of the cans.
(Answers will vary.)

d. How much heat was released by the air in the can with the tubing?
(Answers will vary.)

5. Analyze the design of this experiment by answering the following questions:
   a. How can the flow of icy water be controlled?
      (Answers will vary, but may include: add a clamp or change the size of the tubing.)

   b. Suggest a way to maintain a constant temperature inside the can with the tubing.
      (Answers will vary, but may include: add insulation.)

   c. What would happen if you moved the light source closer to the can? What real world problem might this simulate?
      (Temperatures will increase. Answers to real world problems will vary, but may include: astronauts leave the protection of their spacecraft or the International Space Station and are exposed to the intense heat of the sun.)

   d. Explain how a liquid cooling garment could be constructed that could operate continuously without tubing and buckets of ice water that eventually run out.
      (Answers will vary, but may include: use a closed-loop system with a pump or use a coolant other than ice water.)