Activity Four: Build a Heat Shield

Educator Notes

Challenge

Students will work together as a team to design and build a heat shield that will protect the contents (candy) of a crew module (paper cup) from a simulated atmospheric reentry (hair dryer).

Suggested Time

60 minutes

Learning Objectives

Students will

- Apply the steps of the engineering design process to successfully complete a team challenge.
- Design, build, and test a crew module heat shield.
- Explore concepts related to heat transfer, heat load, thermal resistance, and turbulence.
- Brainstorm ideas about what material characteristics will best protect the contents (candy) of the simulated crew module.
- Make observations and collect data to improve their design.

Curriculum Connection

Science and Engineering (NGSS)	
Disciplinary Core Ideas • MS-PS3-3 Energy: Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer. • MS-PS3-4 Energy: Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample. • MS-ETS1-1 Engineering Design: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions. • MS-ETS1-3 Engineering Design: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success. *Crosscutting Concepts* • System and System Models: A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems. • Energy and Matter: Tracking energy and matter flows into, out of, and within systems helps one understand their system's behavior. • Interdependence of Science, Engineering, and Technology: Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems.	*Science and Engineering Practices* • Asking Questions and Defining Problems: A practice of science is to ask and refine questions that lead to descriptions and explanations of how the natural and designed world works and which can be empirically tested. • Developing and Using Models: A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations. • Planning and Carrying out Investigations: Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters. • Analyzing and Interpreting Data: Scientific investigations produce data that must be analyzed in order to derive meaning. Because data patterns and trends are not always obvious, scientists use a range of tools—including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data. Scientists identify sources of error in the investigations and calculate the degree of certainty in the results. Modern technology makes the collection of large data sets much easier, providing secondary sources for analysis.
Technology (ISTE)	
Standards for Students • Knowledge Constructor: Students critically curate a variety of resources using digital tools to construct knowledge, produce creative artifacts, and make meaningful learning experiences for themselves and others. – 3d: Students build knowledge by actively exploring real-world issues and problems, developing ideas and theories, and pursuing answers and solutions. • Innovative Designer: Students use a variety of technologies within a design process to identify and solve problems by creating new, useful, or imaginative solutions. – 4a: Students know and use a deliberate design process for generating ideas, testing theories, creating innovative artifacts, or solving authentic problems.	*Standards for Students (continued)* – 4c: Students develop, test, and refine prototypes as part of a cyclical design process. – 4d: Students exhibit a tolerance for ambiguity, perseverance, and the capacity to work with open-ended problems. • Global Collaborator: Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally. – 7c: Students contribute constructively to project teams, assuming various roles and responsibilities to work effectively toward a common goal.
Mathematics (CCSS)	
Mathematical Practices • CCSS.MATH.PRACTICE.MP1: Make sense of problems and persevere in solving them.	*Mathematical Practices (continued)* • CCSS.MATH.PRACTICE.MP3: Construct viable arguments and critique the reasoning of others.

Preparation Time

15 minutes

- Read the Introduction and Background, Educator Notes, and Student Handout to familiarize yourself with the activity.
- Print copies of the Student Handout.
- Gather and prepare all supplies listed on the materials list.
- The wire mesh or wire cloth (often referred to as "hardware cloth" or "welded wire fabric") can be found online or in local hardware stores. Any type can be used, but ideally it will be able to give structure to the shield device and not conduct the heat. This is a major design element. If the activity budget allows, offer a variety of wire mesh or cloth materials, and students can test to determine which material works best.
- Set up testing stations with safety equipment, hair dryer, tongs, infrared thermometer (recommended), scale, and a metric ruler. One station for every two or three teams is recommended.

Materials

- ☐ Copies of Student Handout and blank paper
- ☐ Paper and pencil
- ☐ Scissors
- ☐ Tape
- ☐ Metric rulers
- ☐ 5-oz paper cups (1 per team)
- ☐ Digital scale or balance
- ☐ Hair dryer (1 per testing station)
- ☐ Tongs (1 per testing station)
- ☐ Stopwatch (1 per testing station)
- ☐ Thermometers (2 per testing station; infrared is recommended)
- ☐ Oven mitts or gloves (2 per testing station)
- ☐ Eye protection (for every student)
- ☐ Unwrapped candy bars without nuts (Mini, nugget, or fun size, at least 2 per team; for consistency, use the same type for the whole class. Nuts interfere with the temperature probes.)

General building supplies (choose a selection of materials to test):

- ☐ Wire mesh or wire cloth (see Preparation Time)
- ☐ Index cards, newspaper, construction paper
- ☐ Cotton balls
- ☐ Bubble wrap
- ☐ Electrical tape
- ☐ Steel wool
- ☐ Spackling compound
- ☐ White glue
- ☐ Styrofoam™ scraps (packing peanuts, food trays, plates)
- ☐ Cardboard scraps (milk cartons, shoeboxes, coffee cups, boxes)

Introduce the Challenge

- Provide context for this activity using the Introduction and Background information in this guide. Use the Additional Resources listed at the end of the Educator Notes to engage

Share With Students

Brain Booster

Avcoat, an ablative material installed on the base of the heat shield, is designed to erode and move heat away from the crew module, protecting the astronauts inside from searing temperatures experienced while reentering Earth's atmosphere.

Learn more: https://www.nasa.gov/content/partnerships-make-missions-possible

On Location

Inside the world's largest vacuum chamber and premier space environments test facility at NASA's Plum Brook Station in Sandusky, Ohio, spacecraft are subjected to extreme temperatures, ranging from –160 to 150 °C (–250 to 300 °F), to simulate extreme in-space conditions. The facility also has the capability to test for electromagnetic interference and compatibility.

Learn more: https://www.nasa.gov/feature/orion-to-face-simulated-rigors-of-space-in-last-major-testing-before-artemis-i and inform students about this challenge. Emphasize why a heat shield is a crucial element of a spacecraft, especially one that carries people.

- Explain the role of engineers in designing technology to solve problems. Share the NASA for Kids video Intro to Engineering and introduce the engineering design process.
- Explain that engineers not only seek to solve problems, they also look for designs that are cost effective and can be developed in a reasonable time period.
- Divide the class into teams (three to five students) and distribute the Student Handout to each team. Explain the details of the challenge, including the design constraints and your expectations for teamwork and classroom management.

Design Constraints

1. The surface area of the heat shield cannot exceed 40 cm^2.
2. The heat shield must protect the interior contents of the crew module (candy) from heat and turbulence during the simulated reentry (hair dryer).
3. The contents must survive for 7 minutes without melting.

Facilitate the Challenge

Ask, Imagine, and Plan

- Discuss the concepts of heat transfer, heat load, thermal resistance, friction, and turbulence.
- Engage teams to brainstorm ideas about what material characteristics will work best to protect the contents (candy) of the simulated crew module.
- Encourage students to draw out their ideas for a heat shield and plan how they will conduct the testing.

Create, Test, and Improve

1. Each team of students will build the heat shield they designed, using the materials provided.
2. Once the heat shield has been built, students will test the shield by holding a hair dryer no more than 10 cm away from the bottom of the shield, exposing it to direct heat and air for 7 minutes.

   Safety

   - To prevent burns, students should use tongs and oven mitts or gloves to hold the heat shield and hair dryer.
   - Use caution when operating hair dryers. Do not touch the hot parts of the hair dryer or heat shield.
   - Be aware of candy and nut allergies. Other materials such as wax or ice could be used instead of candy bars.
3. Students will use a stopwatch and take thermometer readings in 1-minute increments. They will track their data on the Student Handout.
4. After completing the first round of testing, students will make modifications to their designs to improve protection of the crew module contents (candy) based on the results of the testing and their understanding of scientific concepts, including transfer of energy, thermal resistance, and heat transfer.
5. Students will repeat the testing with their modified design.

Share

Engage students with the following discussion questions:

- Which design characteristics provided the most protection to the crew module?
- In what ways were you able to manage your time in order to get the best results?
- What information could engineers working on this project learn from your team's results?
- What other tests or calculations could you do before making your recommendations to NASA's engineering team?

Extensions

- Repeat the activity using different types of heat-sensitive materials, such as wax or ice, as your "cargo" inside the crew module (instead of candy).

- Add a cost constraint to the challenge and create a budget for students to "purchase" materials. Assign cost to all materials based on mass, area, or type of material.
- Ask teams to determine under what conditions their design will fail, or the maximum heat load on their design.

Reference

Modified from Mars Science Laboratory Entry, Descent, and Landing Instrument (MEDLI) activity: https://www.nasa.gov/sites/default/files/best_medli_workbook.pdf

Additional Resources

- Web page: Orion Spacecraft. https://www.nasa.gov/exploration/systems/orion/index.html
- Photo: Orion's heat shield. https://www.nasa.gov/image-feature/heat-shield-for-first-artemis-mission-with-astronauts-arrives-at-kennedy
- Video: Orion: Heat Shield. https://www.youtube.com/watch?v=XH4VVpfr9Bs
- Video: Career Connection: NASA Heat Shield Engineer. https://www.youtube.com/watch?v=qmDIp6FW2eE
- Digital Badging: Online NASA STEM Learning. https://www.txstate-epdc.net/digital-badging/

Artist's rendering of Orion spacecraft reentry. (NASA)

Activity Four: Build a Heat Shield

Student Handout

Your Challenge

Design a heat shield to protect the contents of a crew module during a simulated atmospheric reentry.

Design Constraints

1. The surface area of the heat shield cannot exceed 40 cm^2.
2. The heat shield must protect the interior contents of the crew module (candy) from heat and turbulence during the simulated reentry (hair dryer).
3. The contents must survive for 7 minutes without melting.

Ask, Imagine, and Plan

- You will be given a paper cup to serve as the crew module and a small piece of candy to simulate the sensitive contents within the crew module.
- After the heat shield is built, it needs to be securely attached to the open end of the cup (the bottom of your crew module) with the unwrapped piece of candy inside.
- Your team will be responsible for documenting observations and temperatures (internal and external) once per minute. Include in your design a window or hole in the top of the crew module so you can observe any changes.
- Brainstorm ideas and sketch your heat shield on the blank paper your teacher provided. Be sure to label it with the materials you plan on using. What is the general shape of your heat shield? What types of material will best protect the contents inside?

Create

- Build your heat shield using only the materials provided.

Test and Improve

1. You will conduct a 7-minute test on the heat shield under the direction and supervision of your teacher. For safety, use tongs when handling the crew module and heat shield. The heat source (hair dryer) should not be more than 10 cm from the bottom of the heat shield.
2. On a sheet of paper, create a table like the example shown below. At 1-minute intervals, note your observations of what is happening to the candy while the test is taking place. Use the thermometer to take temperature readings of the inside of the module and the bottom of your heat shield. Record your results and observations in your table.

Time increments (minutes)	External temperature (C or °F)	Internal temperature (C or °F)	Observations
1:00			
2:00			
3:00			
4:00			
5:00			
6:00			
7:00			

Fun Fact

Did you know that Orion reentered Earth's atmosphere at a speed of more than 32,000 km/h (20,000 mph) before splashdown during Exploration Flight Test 1? The heat shield endured temperatures of nearly 2,200 °C (4,000 °F), which is almost twice as hot as molten lava!

Learn more: https://www.youtube.com/watch?v=KyZqSWWKmHQ

Career Corner

If you become a scientist or engineer in NASA's Advanced Thermal Technologies branch, you can research how various materials could be used to regulate and maintain safe temperatures inside a spacecraft, protecting the crew and the equipment in the extreme environment of space.

Learn more: https://www.nasa.gov/careers/engineering

3. Improve the design of your heat shield and repeat the experiment. Make another table like the one above and record your new results and observations.

Share

- Which design characteristics provided the most protection to the crew module contents?
- In what ways were you able to manage your time in order to get the best results?
- NASA engineers must also determine under what conditions their designs might fail. By learning the maximum heat load on their design, engineers can identify what other conditions this technology could be used with (hotter temperatures, longer reentries, etc.). Based on the data you collected in the 7-minute tests, how much longer do you think your design would be able to handle the turbulence and thermal stress?

Installation of the heat shield on NASA's Orion spacecraft crew module at Kennedy Space Center in Florida on July 25, 2018. (NASA/Kim Shiflett)