National Aeronautics and Space Administration

Landing Humans on the Moon

Educator Guide

EARTH AND SPACE SCIENCE

Next Gen STEM – Moon to Mars

For more about Next Gen STEM visit https://www.nasa.gov/stem/nextgenstem/moon_to_mars

Education Product	
Educators and Students	Grades 6-8

Contents

Preface

Landing Humans on the Moon was published by NASA's Office of STEM Engagement as part of a series of educator guides to help middle school students reach their potential to join the next-generation STEM workforce. The activities can be used in both formal and informal education settings as well as by families for individual use. Each activity is aligned to national standards for science, technology, engineering, and mathematics (STEM), and the NASA messaging is current as of April 2021.

STEM Education Standards

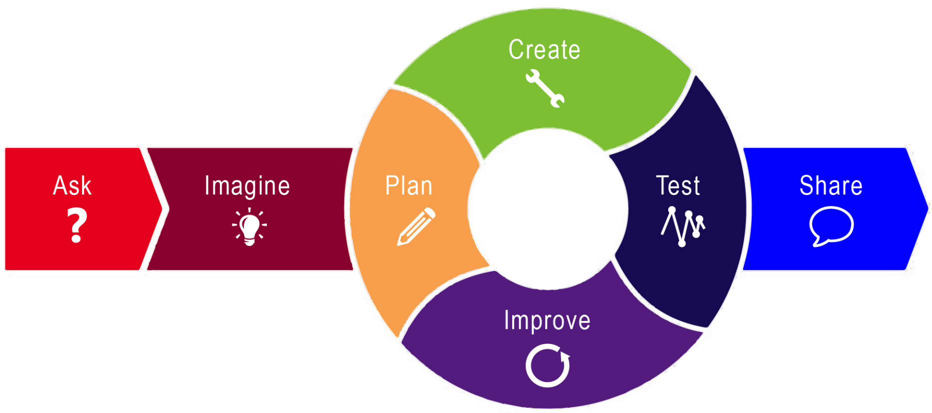
The STEM disciplines matrix shown below aligns each activity in this module to standards for teaching STEM according to four primary focus areas within each discipline. The four focus areas for science were adapted from the Next Generation Science Standards (NGSS) disciplinary core ideas. The four focus areas for technology were adapted from the International Society for Technology in Education (ISTE) Standards for Students. The four focus areas for engineering were adapted from the National Science Teaching Association (NSTA) and NGSS science and engineering practices. The four focus areas for mathematics were adapted from the Common Core State Standards (CCSS) for Math content standards by domain.

Activity	STEM Disciplines															
	Science				Technology				Engineering				Math			
	NGSS Disciplinary Core Ideas				ISTE Standards for Students				NSTA and NGSS Practices				CCSS Content Standards by Domain			
	Physical Sciences	Life Sciences	Earth and Space Sciences	Engineering, Technology, and the Application of Sciences	Knowledge Constructor	Innovative Designer	Computational Thinker	Creative Communicator	Ask Questions and Define Problems	Develop and Use Models	Plan and Carry Out Investigations	Analyzing and Interpreting Data	Ratios and Proportional Relationships	The Number System	Expressions and Equations	Geometry
Choose Your Landing Site		✓			✓		✓	✓	✓			✓				✓
Sculpting Lunar Geology			✓		✓		✓	✓		✓		✓	✓			
Priority Packing for the Moon		✓			✓		✓	✓	✓			✓				✓
Safe Landing on the Lunar Surface	✓			✓		✓	✓				✓	✓		✓	✓	✓

Engineering Design Process

The engineering design process (EDP) is crucial to mission success at NASA. The EDP is an iterative process involving a series of steps that engineers use to guide them as they solve problems. Students can use the seven steps outlined below for many of the activities in this guide. Learn more about the EDP with NASA's Educator Professional Development Collaborative at https://www.txstate-epdc.net/models-of-the-engineering-design-process/.

1. **Ask**: Identify the problem, the requirements that must be met, and the constraints that must be considered.
2. **Imagine**: Brainstorm solutions and research what others have done in the past.
3. **Plan**: Select and sketch a design.
4. **Create**: Build a model or a prototype.
5. **Test**: Evaluate solutions by testing and collecting data.
6. **Improve**: Refine the design.
7. **Share**: Communicate and discuss the process and solutions as a group.

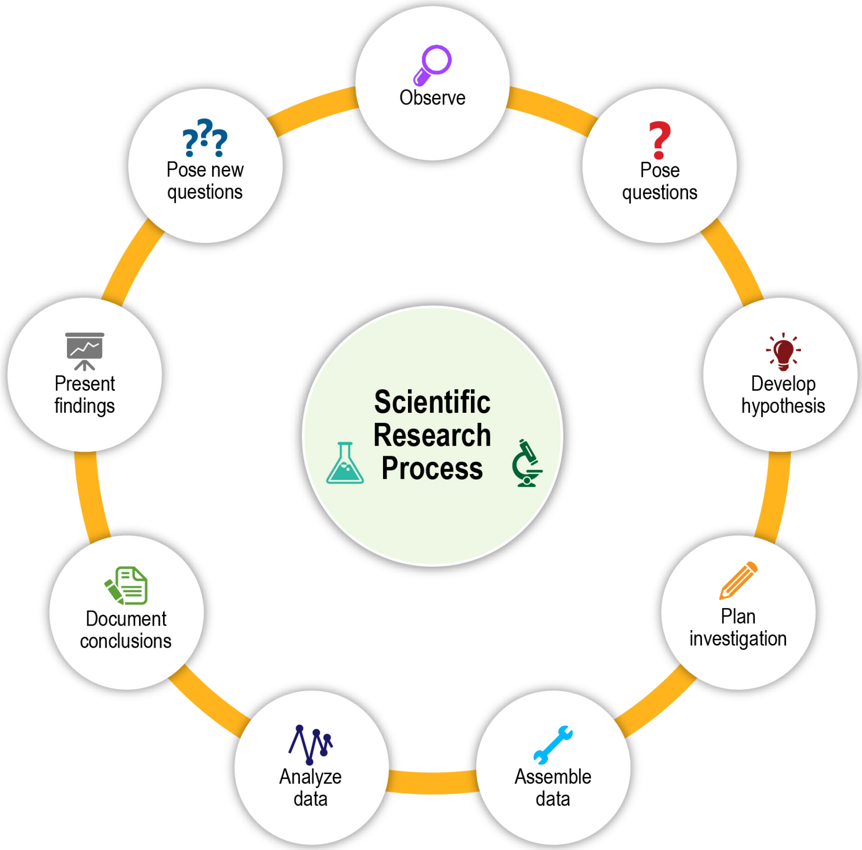


Scientific Research Process

The scientific research process (SRP) is a way to represent the sorts of things scientists do every day, regardless of whether they are chemists, astronomers, or physicists. The nine steps in the process are outlined below. Students can repeat these steps as many times as necessary, depending on the time available for the activity.

1. **Observe**: Begin the scientific research by using the five senses to make observations, identifying a problem that needs to be solved or a phenomenon that needs to be understood.
2. **Pose Questions**: Based on observations, brainstorm possible questions that are interesting and can be answered in the time available for the module.
3. **Develop Hypothesis**: Suggest an answer to the chosen question/s based on what is already known. A useful hypothesis is a testable, measurable statement.
4. **Plan Investigation**: Outline how data will be collected (where, when, and how) to ensure that the data collected will answer the question and test the hypothesis. Useful data must also be precise (repeatable), so measurements must be performed the same way each time.
5. **Assemble Data**: Following the investigation plan, take the measurements of data.
6. **Analyze Data**: Construct graphs or charts to help look for patterns and trends in the data. Data analysis often involves comparing data from different times and places and looking for patterns and different types of variations.
7. **Document Conclusions**: Carefully review what was performed during the investigation. Concentrate on any trends that may have been noticed when the data were analyzed. Look at any graphs that were made. Based on the data collected, make a statement about what was learned from the data collection. Was the hypothesis supported? Explain why or why not.

8. **Present Findings**: Share the research results with peers and the community. This is a very important step for scientists. This can take many forms, such as a science fair or a poster presentation.
9. **Pose New Questions**: Think about and record other questions that have been raised by this investigation and how to answer them. It is rare that a scientific question is answered by just one experiment or investigation.



Teamwork

Everyone is a scientist and an engineer! It is important that everyone on the team be able to participate and contribute throughout these activities. If one student does all the building, the other students may be very bored during the building process. If one student is the leader, other students may not have a chance to share their ideas. Here are some possible roles that students can take:

Student Role	Description
Communications and Outreach	Takes notes of all team decisions and actions for use in a final presentation. If a camera is available, takes video and/or photos throughout the investigation or challenge for use in a final presentation.
Logistics	Makes sure that the team has all the resources they need, that resources are distributed fairly, and that the team knows when resources are running low.
Mission Assurance	Makes sure the team is following the plan. Keeps track of time and makes sure that everyone has a chance to have their voice heard.
Safety	Ensures all team members are wearing their safety goggles and following safety protocols.

Curriculum Connection

In this module, students will be exploring the Moon. They will learn about the history and geology of the Moon and its similarities to Earth, and they will simulate the process NASA will use to choose an appropriate human landing site, weighing the advantages and disadvantages. Students will have to consider both biological needs and geometry as they decide what they would bring with them to the Moon for exploration and survival when packing space is extremely limited. Then, using engineering design principles, students will mirror the process that NASA engineers follow to brainstorm a human lander design, ultimately building an actual model that they will test. This guide will challenge students to think critically and work cooperatively in teams to successfully complete each of the tasks put in front of them, just as they will need to do in their future careers.

Over its 60-year history, NASA has created many unique and innovative technologies to fulfill its mission needs. Although many of the technologies developed by NASA do not end up in students' homes, some of the high-tech advances work their way into goods and services students may take for granted. NASA technology is almost everywhere we look! Share the following examples with students to help tie in this educator guide with their everyday lives.

Advanced Water Filtration

NASA has recently discovered unexpected sources of water on the Moon and Mars. Even so, space remains a desert for human explorers, and every drop must be recycled and reused. A nanofiber filter devised to purify water in orbit is currently at work on Earth in devices that supply water to remote villages and in a water bottle that lets hikers and adventurers stay hydrated using streams and lakes. Learn more: https://spinoff.nasa.gov/Spinoff2013/cg_1.html

Phase-Change Materials

NASA-funded research on next-generation spacesuits includes the development of phase-change materials. These materials can absorb, hold, and release heat to keep people comfortable. This technology is now found in blankets and comforters, bedsheets, dress shirts, T-shirts, undergarments, and other common household products. Learn more: https://spinoff.nasa.gov/Spinoff2012/cg_3.html

Introduction and Background

As part of the Artemis missions, NASA plans to land the first woman and the first person of color on the Moon, using innovative technologies to explore more of the lunar surface than ever before. NASA will collaborate with commercial and international partners to establish sustainable exploration by the end of the decade. Using what we learn from living on and around the Moon will help us take the next giant leap—sending astronauts to Mars.

In April 2020, NASA selected three U.S. companies to develop human landing systems for the Artemis missions: Blue Origin, leading a team that includes Lockheed Martin, Northrop Grumman, and Draper; Dynetics (a Leidos company); and SpaceX. NASA's Artemis missions will reveal new knowledge about the Moon, Earth, and our origins in the solar system. NASA and its partners will be able to fine-tune precision landing technologies and develop new mobility capabilities that allow robots and crew to travel greater distances and explore new regions of the Moon. The Artemis human landing system is a vital part of NASA's deep space exploration plan, along with the Space Launch System (SLS) rocket, the Orion spacecraft, and the Gateway orbiting outpost. After the initial landing, NASA will begin conducting regular surface missions, sending rovers and a habitat to the lunar surface in order to test new power systems and begin preparations for human exploration of Mars.

Illustration of Artemis astronauts on the Moon. (NASA)

History and Geology of the Moon

When astronauts explored the surface of the Moon from 1969 to 1972, they were doing more than digging up rocks and lunar sediment. The astronauts were getting a glimpse into the past—retrieving clues about the formation of our Earth and Moon, learning about the intensity of early impacts and bombardment from meteorites and the variation of those impacts over time, and even discovering the history of our Sun. Here on Earth, geological activity has made this sort of discovery more difficult. Our planet is so geologically active that most of its early history has been erased by mountain building, weathering, erosion, colliding tectonic plates, and volcanism. In contrast to Earth, the Moon does not experience much geological activity. The lunar plains, valleys, and rocks are preserved essentially as they were originally formed long ago. The Moon is also easier to reach than our closest planets in terms of collecting samples and data about the formation of our solar system. Starting with Apollo 11, astronauts explored the surface of the Moon at six unique landing sites on the Moon's nearside, or Earth-facing side. The Artemis missions plans to send astronauts to the lunar South Pole region to access persistently shadowed terrain where resources have not been affected in billions of years and can be mined and studied.

Some of the planetary processes that scientists have discovered are differentiation, volcanism, impacts, and accretion. *Differentiation* occurs when planets begin to melt and the materials in them begin to separate due to varying densities. On the Moon, the heaviest materials sink to form cores and the low-density magma rises to form crusts. The magma ocean produced what we see today in the lunar highlands, the light-colored, heavily cratered regions of the Moon. *Volcanism* created the Moon's smooth, dark regions. Scientists have evidence that suggests that for the first 600 million years of the Moon's existence, large asteroids and comets continued to strike the Moon, but details about these *impacts* remain a mystery. During the early formation of the planets and moons of our solar system, smaller asteroids were drawn together by gravity, a process known as *accretion*. The prevailing theory of our Moon's formation is that a planet about the size of Mars collided with the early Earth, knocking a large portion of Earth's material into the void of space. That material accreted together over about a month's time while remaining in orbit around the Earth. Since then, the Moon has continued to slowly drift away from Earth at the rate of 3.78 centimeters (1.48 inches) per year while under constant bombardment by meteorites and comets. It is time to return to the surface of the Moon to learn more about our celestial sister and develop and test the technologies that will allow us to explore deeper into our solar neighborhood. Learn more about the Moon's history in the NASA video "Evolution of the Moon": https://www.youtube.com/watch/UIKmSQqp8wY

Lunar Surface Activities

The Apollo astronauts were on the lunar surface for just 2 days on average. For future Artemis missions, longer stays on the Moon are expected. Longer duration missions provide more data for human research, more time for scientific work, and more experience for future exploration missions. This is the proving ground that will refine our technologies to live and work in deep space, learn more about planetary processes and evolution, and establish the resources and infrastructure to support further scientific investigations.

Earlier launches to the Moon will be robotic missions to deliver science and technology payloads before the arrival of astronauts. NASA's Volatiles Investigating Polar Exploration Rover, or VIPER, will scout out water ice and attempt to reach some of the most promising ice reserves. This will be the first opportunity to explore the polar craters for volatiles—water ice and other compounds—that are believed to exist there based on evidence from orbiting reconnaissance satellites. A series of launches to the Moon will follow, either for delivery of cargo landers or for astronauts to practice orbiting capabilities and, eventually, landing and launching from the surface.

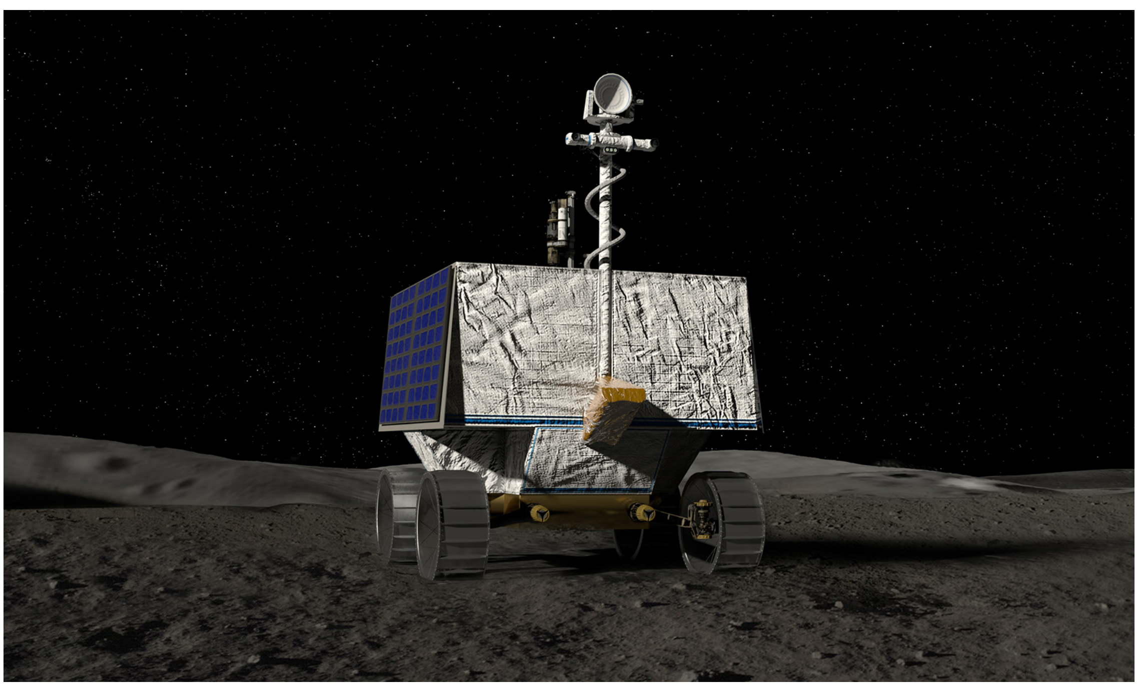


Illustration of NASA's Volatiles Investigating Polar Exploration Rover, or VIPER. (NASA)

Human Landing System Program

The objective of the Human Landing System program is to deliver humans to the surface of the Moon and return them safely back to lunar orbit. The lander will also carry equipment and supplies that will allow astronauts to spend time on the surface performing various tasks. These lunar landers will work together with the Space Launch System (SLS) rocket, the Orion spacecraft, and the Gateway outpost in lunar orbit to form a lunar architecture for long-term human exploration on and around the Moon.

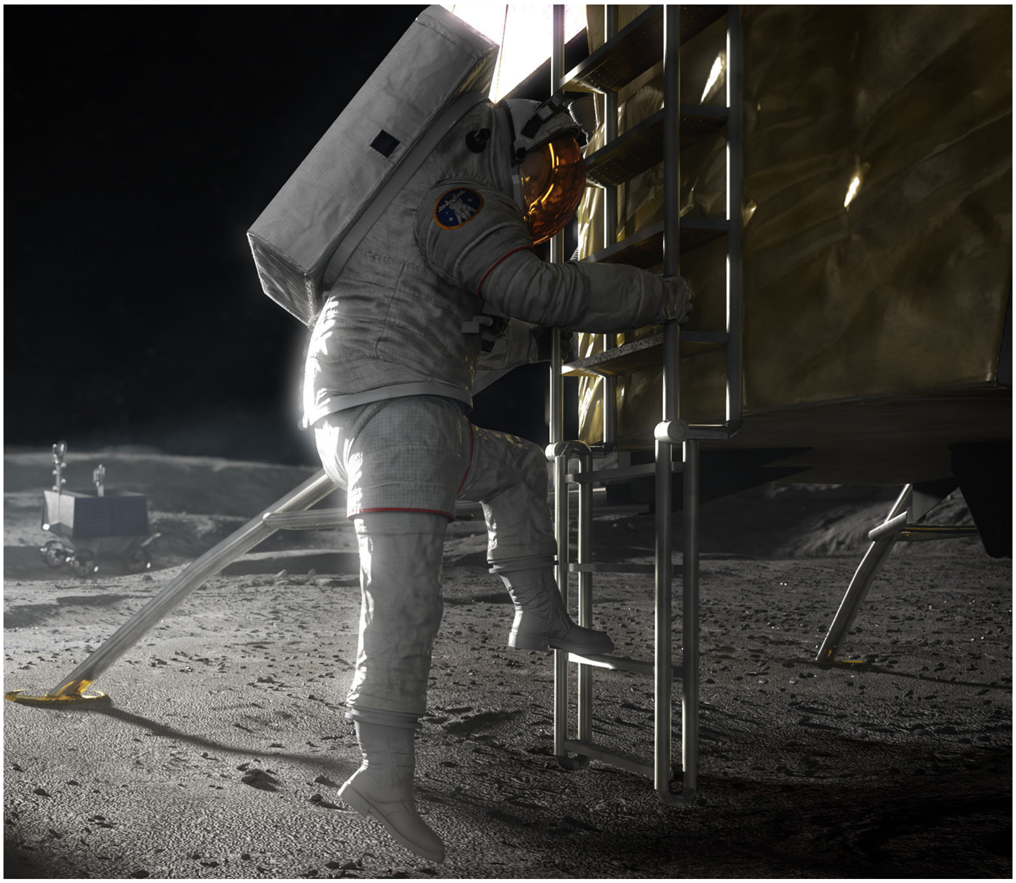


Illustration of Artemis astronaut stepping off lunar lander. (NASA)

Activity One: Choose Your Landing Site

Educator Notes

Learning Objectives

This activity provides Site Information sheets and guiding questions to give students an opportunity to compare and contrast various lunar landing sites for suitability as a potential base camp for humans, considering factors such as geology, resources, communication with Earth, and average surface temperatures to determine the most suitable landing site.

Students will utilize the scientific research process to

- Construct an evidence-based argument about which site is most suitable based on NASA data.
- Convert temperatures from kelvin to Fahrenheit.
- Perform calculations such as surface area and volume in support of their argument.

Investigation Overview

Students are asked to select an appropriate human landing site on the Moon using NASA topographic maps and data. They must consider that different lunar locations will have different resources and conditions. Students must weigh the benefits versus the risks to select the best landing site.

Suggested Pacing

1 to 2 hours

National STEM Standards

Science and Engineering (NGSS)	
Disciplinary Core Ideas • MS-LS2-1 Ecosystems: Interactions, Energy, and Dynamics: Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem. *Crosscutting Concepts* • Scale, Proportion, and Quantity: In considering phenomena, it is critical to recognize what is relevant at different size, time, and energy scales, and to recognize proportional relationships between quantities as scales change. • Stability and Change: For both designed and natural systems, conditions that affect stability and factors that control rates of change are critical elements to consider and understand. *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.	*Science and Engineering Practices (continued)* • 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. • Engaging in Argument From Evidence: Argumentation is the process by which explanations and solutions are reached. • Obtaining, Evaluating, and Communicating Information: Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical professional activity.
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. • Computational Thinker: Students develop and employ strategies for understanding and solving problems in ways that leverage the power of technological methods to develop and test solutions.	*Standards for Students (continued)* • Creative Communicator: Students communicate clearly and express themselves creatively for a variety of purposes using the platforms, tools, styles, formats, and digital media appropriate to their goals.
Mathematics (CCSS)	
Content Standards by Domain • CCSS.MATH.CONTENT.7.G.B.6: Solve real-world and mathematical problems involving area, volume, and surface area of two- and three-dimensional objects composed of triangles, quadrilaterals, polygons, cubes, and right prisms. (Extension Exercise)	*Content Standards by Domain (continued)* • CCSS.MATH.CONTENT.8.G.C.9: Know the formulas for the volumes of cones, cylinders, and spheres and use them to solve real-world and mathematical problems. (Extension Exercise)

Activity Preparation

The educator should

- Read the introduction and background information, Educator Notes, Lunar Map, five Site Information sheets, and Moon Matrix and Temperature Conversion Worksheet to become familiar with the investigation.
- Print the Site Information sheets for each team (preferably on cardstock paper, or have the sheets laminated).
- Print the Lunar Map for each team (preferably on cardstock paper, or have the sheets laminated).
- Print the Moon Matrix and Math Extension Worksheet for each student.
- Prepare five landing site stations in the room, one station per landing site. Each station should have one Site Information sheet and markers, colored dot stickers, or colored sticky notes for the "Go," "No Go," or "Need More Data" categories (e.g., use a green marker or sticker for "Go," red for "No Go," and yellow for "Need More Data").

Materials

For each team (3 to 5 students):

- Moon and Matrix Temperature Conversion Worksheet for each student
- Full-color Lunar Map of the lunar South Pole with marked landing sites
- Access to a computer or tablet for creation of final presentation or for extension activity using the Moon Trek website at https://trek.nasa.gov/moon/#v=0.1&x=0&y=0&z=1&p=urn%3Aogc%3Adef%3Acrs%3AEPSG%3A%3A104903&d=&locale=&b=moon&e=-269.999994963537%2C-126.91406013260008%2C269.999994963537%2C126.91406013260008

For each lunar landing site station (up to 5):

- Site Information sheets (on cardstock paper)
- Markers, dot stickers, or sticky notes in three different colors

Safety

Ensure students take their time moving between landing site stations to prevent accidents.

Introduce the Investigation

Inform students that they will be selecting an appropriate landing site on the South Pole of the Moon using NASA topographic maps and data. Remind students that each landing site has different types of resources and advantages versus disadvantages. Review the following selection criteria:

Selection Criteria
Students must pick only one landing site located on the lunar South Pole.
Students must weigh the benefits versus the risks of a landing site that contains resources for astronauts.
Students must justify a site where there are sufficient resources.

Facilitate the Investigation

Pose Question

Give students the following scenario:

> You have been told that you are going on a field trip far away from home for the weekend to learn about ecosystems. You know that the place is in a rural area, the weather will be warm, and you will be surrounded by a swamp. What items would you take with you to be comfortable?

Create a graphic organizer with students' responses.

Develop Hypothesis

Explain that astronauts will live in the crew cabin of the human landing system while they are on the Moon's surface.

- Have students think about what they know about the basic needs of humans. What resources will astronauts need to bring with them, and what could they find on the surface?
- Have students look at the Lunar Map with the five predetermined landing sites. Based on the teams' discussion about human needs and resources, they should choose a site they believe will meet most of the needs they have discussed.
- If students are having difficulty formulating a testable hypothesis, provide them with the following prompt: "I predict the best location is going to be ______, because _______."

Plan Investigation

- After setting up stations with the additional information for each of the five landing sites, randomly assign each team to one of the five sites.
- Students will look through the Site Information sheets to make an informed decision about their choice for a suitable landing site.
- Discuss the following priorities that NASA requires of a landing site:
  1. Access to sunlight for long periods of time. The temperature of the Moon drops significantly when in shadow.
  2. Direct view of Earth. This will help prevent communications disturbances.
  3. Surface conditions and slopes that are safe for landing systems and for robotic and astronaut travel.
  4. Access to permanently shadowed regions where water ice and other compounds are located. Astronauts may be able to utilize water ice and resources in the depths of these ancient craters that have been untouched throughout time.

Assemble Data

- Using the Moon Matrix and Temperature Conversions Worksheet, each student will record pertinent data from all five sites that will aid in making an informed decision about the most suitable landing site. Students will then discuss their individual findings in their teams.
- Before giving students the Temperature Conversions Worksheet, a concept review of negative numbers may be necessary.
- Ask student teams to rotate through all five landing stations and look through the Site Information sheets.

Analyze and Document Conclusions

- After each team visits and records data from all five of the landing stations, have students discuss their findings and determine which landing site their team agrees is the most suitable.
- Students should compare their final decision with their original hypothesis.
- Each team should mark their chosen site on the Lunar Map and defend their selection by answering the question posed on the Moon Matrix handout.

Share With Students

Brain Booster

The pressure suits worn by the Apollo astronauts greatly restricted their mobility while working on the Moon, including their ability to bend over. To aid the astronauts, special tools were designed to allow them to collect rocks and soil samples to take back to Earth for study. These sample collection sites were carefully planned out prior to the start of each mission as well. Artemis astronauts will wear new spacesuits designed for greater mobility and enhanced communications. Explore the Apollo photo gallery for images of lunar excavation tools and check out NASA's Suit Up page for more about the Artemis Generation spacesuit.

Learn more:
https://www.flickr.com/photos/projectapolloarchive/albums
https://www.nasa.gov/suitup

On Location

Take a field trip to the Moon! Explore human landing sites, robotic missions, geography, and more with this interactive website. Investigate the Moon with your students and learn about other valuable resources, the current phase and temperature of the Moon, and much more.

Learn more:
https://moon.nasa.gov/

Present Findings

Student teams can present their findings and conclusions to the whole group in a variety of ways, depending on the amount of time remaining. Suggestions include a debate, a question-and-answer session, or travel advertisements. Regardless of the format, presentations should be made using computer software or video. Ensure that whatever method is chosen for the discussion, students defend their choices using hard data and logical reasoning.

- What are the advantages/disadvantages of the site you have chosen?
- What resources are available to the astronauts at your landing site?
- Did you obey all the selection criteria for this activity?
- How did your calculations inform your decision?
- Was your final decision the same as your prediction?
- Do you have enough supporting evidence that NASA would agree with the site your team has chosen?
- How would you generate a rating system to make sure that the site picked will ensure success for the mission?

Optional: Share student results on social media using #NextGenSTEM. Be sure to include the module and activity name.

Extensions and Differentiations

- Using the Moon Trek application (see References), guide students to generate a three-dimensional (3D) profile of their landing site and create a model to be printed on a 3D printer.
- Conduct a lesson on creating topographical maps. https://spaceplace.nasa.gov/topomap-clay/en/
- Use the Math Extension Worksheet for an increased emphasis on math.
- Print directions to help students who may need additional structure for this activity.

Reference

Mission Moon Activity
https://www.lpi.usra.edu/education/explore/LRO/activities/mission_moon/

Resource

Moon Trek Website
https://trek.nasa.gov/moon/#v=0.1&x=0&y=0&z=1&p=urn%3Aogc%3Adef%3Acrs%3AEPSG%3A%3A104903&d=&locale=&b=moon&e=-224.99999580294752%2C-106.52343551295796%2C224.99999580294752%2C106.52343551295796

Activity One: Choose Your Landing Site

Student Handout

Your Investigation

You will select an appropriate landing site for astronauts on the South Pole of the Moon by using NASA topographic maps and data to compare resources and conditions at five locations for a potential base camp for humans.

Selection Criteria
You must pick only one landing site located on the lunar South Pole.
You must weigh the benefits versus the risks of a landing site that contains resources for astronauts.
You must justify a site where there are sufficient resources.

Pose Question

NASA is exploring the South Pole region of the Moon.

- What resources would astronauts living on the Moon need to survive? Use what you know about basic human needs to defend your answers.

Develop Hypothesis

Astronauts will live in the crew cabin of the human landing system while they are on the Moon's surface.

- Look at the Lunar Map, which shows five predetermined landing sites on the lunar South Pole. Based on your team's discussion about human needs and resources, choose a site your team believes will meet most of the needs you have discussed.
- Having access to persistently shadowed areas and regions of extremely cold temperatures of the Moon is very important for scientific exploration.
- If you are having difficulty formulating a hypothesis, you can use the following prompt: "I predict the best location is going to be ______, because _______."

Plan Investigation

You will randomly be assigned to begin at one of the five landing stations. You will use the Site Information sheets and the Moon Matrix sheet to help you make an informed decision about your hypothesis after visiting all five landing stations.

- There are a few priorities that NASA requires of a landing site:
    1. Access to sunlight for long periods of time
    2. Direct view of Earth to help with communications
    3. Surface conditions and slopes that are safe for landing systems and for robotic and astronaut travel
    4. Access to permanently shadowed regions where water ice and other compounds are thought to be located

Fun Fact

The Lunar Flashlight is the first CubeSat that will reach the Moon using green propulsion, which is less toxic and more efficient than traditional fuels. This very small spacecraft will be launched on the Space Launch System as part of the Artemis I mission. The Lunar Flashlight will map the lunar South Pole for volatiles, like water ice and other compounds, and will use lasers to look for water ice.

Learn more:
https://www.jpl.nasa.gov/cubesat/missions/lunar_flashlight.php

Career Corner

Adriana Ocampo is a scientist at NASA Headquarters. Adriana was born in Colombia and raised in Argentina, and her family moved to the United States when she was 14. As a planetary geologist, Adriana studies how planets, moons, and asteroids form and evolve over time. She started her career by volunteering at the Jet Propulsion Laboratory after her junior year of high school. Her current job allows her to work on many NASA missions.

Adriana Ocampo

Learn more:
https://solarsystem.nasa.gov/people/1780/adriana-ocampo/

Assemble Data

- Using the Moon Matrix and Temperature Conversions Worksheet, you will record data from each of the five stations that will aid you in making an informed decision about the most suitable landing site.
- The Temperature Conversions Worksheet will allow you to convert temperatures from kelvin to Fahrenheit.
- You will rotate through all five landing stations and look through the Site Information sheets for data.
- You will mark the landing site as “Go,” “No Go,” or “Need More Data” using the colored dots or markers provided.

Analyze and Document Conclusions

- Explain to your team the details you have found about the different landing sites.
- Defend the landing site you have chosen based on the data you have gathered from each station.
- Decide as a team what landing site you will pick. Mark the site on your Lunar Map and list the reasons why the team selected this site.
- Compare your final decision with your original hypothesis.

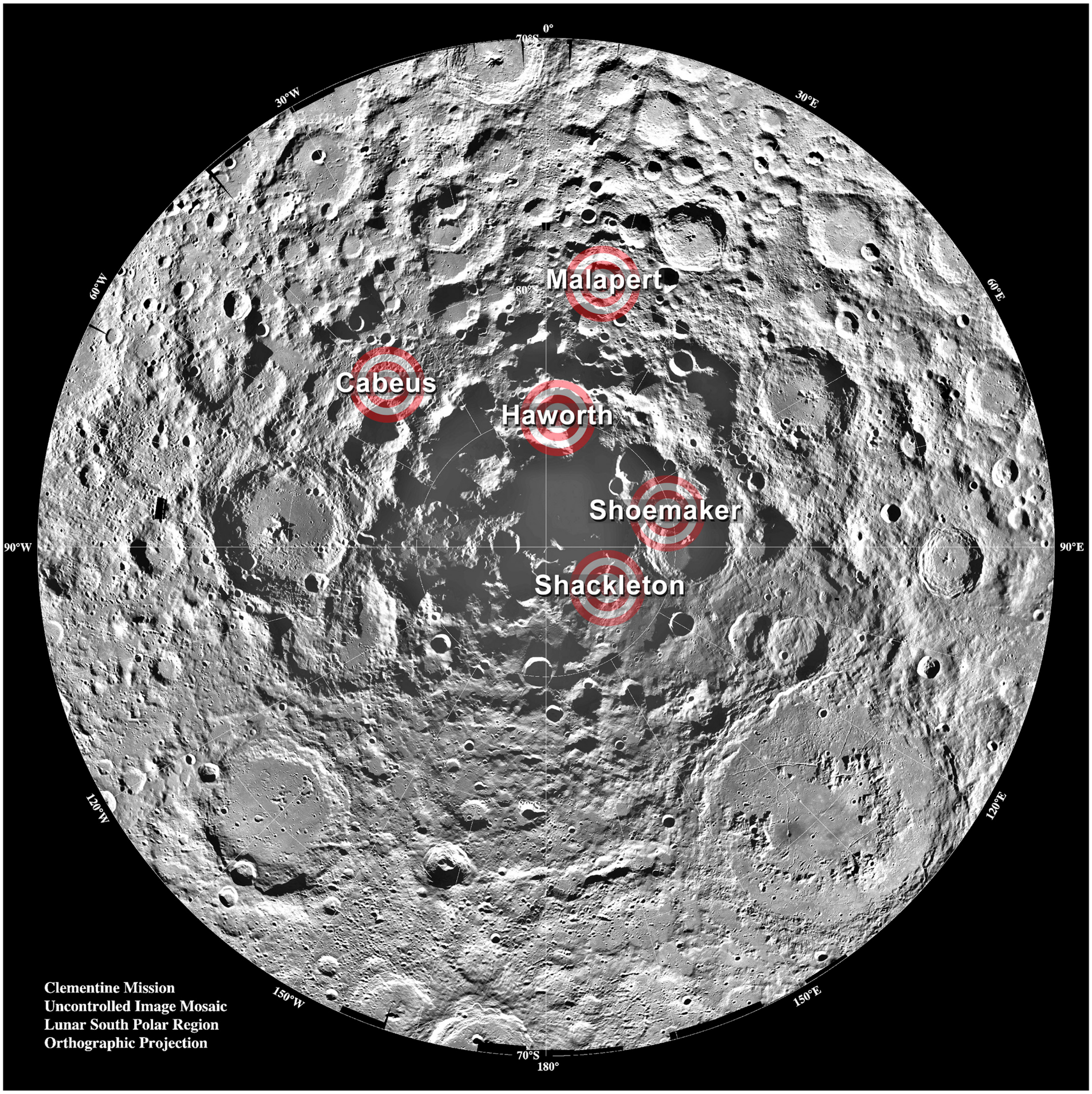
Present Findings

You have been provided instructions for presenting your findings. As you present why you chose your landing site, be sure to answer the following questions:

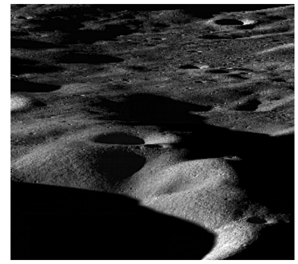
- What are the advantages/disadvantages of the site you have chosen?
- What resources are available to astronauts at your landing site?
- Did you obey all the selection criteria for this activity?
- How did your calculations inform your decision?
- Was your final decision the same as your prediction?
- Do you have enough supporting evidence that NASA would agree with the site your team has chosen?
- How would you generate a rating system to make sure that the site picked will ensure success for the mission?

Lunar Map

Directions: Mark your chosen lunar outpost location. On the Moon Matrix sheet, list the reasons why your team selected this site.



Site Information: Cabeus



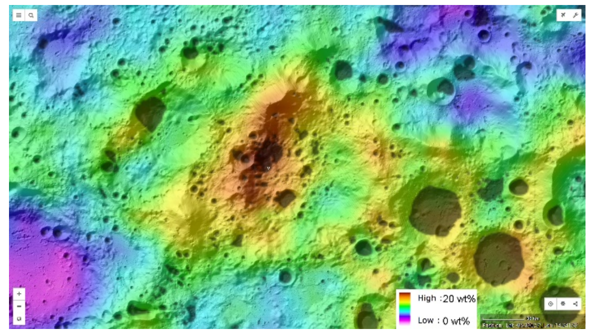
Lunar Reconnaissance Orbiter image of the northern rim of Cabeus. (NASA)

Water and Other Resources

- Contains volatile compounds such as methane, ammonia, and hydrogen gas
- Metals such as sodium, mercury, and silver can also be found here

Topography

- Flat floor with gentle slopes and an absence of large boulders
- Significant areas of permanent shadows
- Diameter: 100 km
- Depth: 4 km
- Shadowed area: 900 km^2



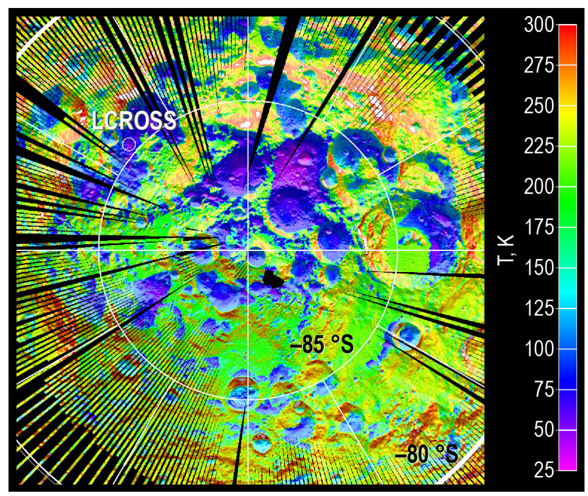
Cabeus region showing the highest concentrations of hydrogen depicted in orange. (NASA)

Temperature

- Extremely cold temperatures that range from 41 to 50 K

General Science

- Concentrations of hydrogen detected by NASA's Lunar Prospector spacecraft
- 5.6 percent of the total mass inside Cabeus is water ice
- Centaur rocket impact site for the Lunar CRater Observation and Sensing Satellite (LCROSS) experiment



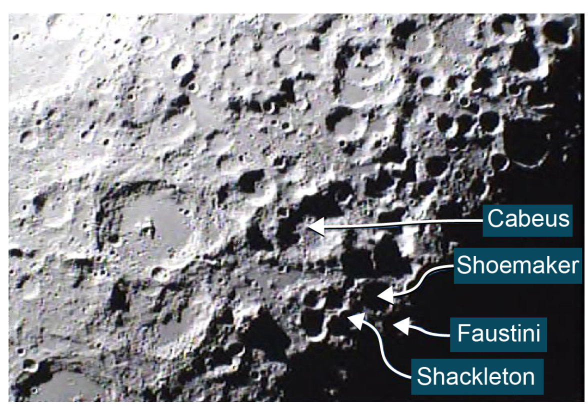
Temperature map of lunar South Pole showing impact site of Centaur rocket for Lunar CRater Observation and Sensing Satellite (LCROSS) experiment. (NASA)

Illumination

- Cabeus is illuminated 1/4 of the Moon's day

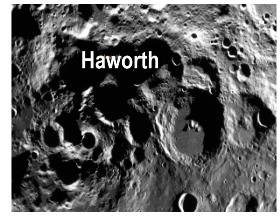
Special Considerations

- A significant portion of the crater's floor is permanently shadowed
- Crater contains water ice and dry ice (frozen carbon dioxide)
- Can be seen from Earth
- The compounds that exist in the crater are the same as those in icy comets



Lunar CRater Observation and Sensing Satellite (LCROSS) visible light camera from altitude of approximately 770 km. (NASA)

Site Information: Haworth



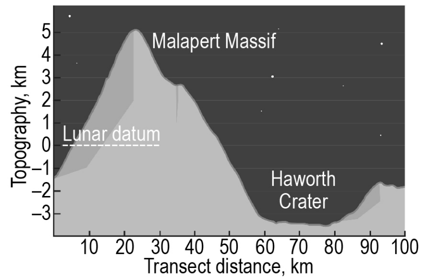
Moon Trek image of Haworth. (NASA)

Water and Other Resources

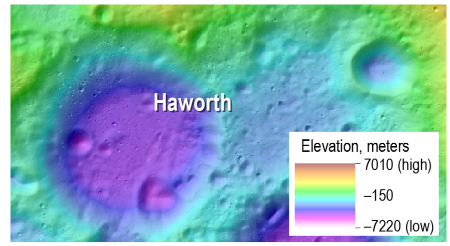
- Water-equivalent hydrogen is 0.15 percent

Topography

- Diameter: 52 km
- Lunar mountains are called *massifs*. There is a massif named Mons Malapert right next to Haworth. The elevation difference between them is close to the height of Mt. Everest!



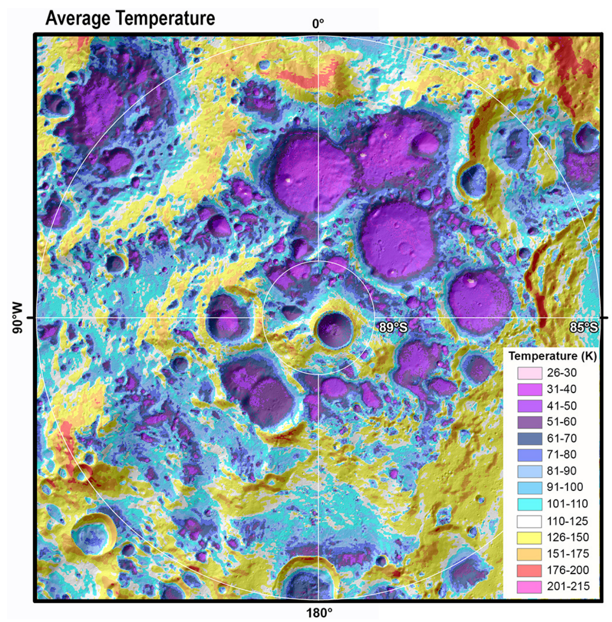
Topography shows a change in elevation that exceeds 8 km. (NASA)



Elevation of Haworth in meters. (Lunar and Planetary Institute, Houston, Texas)

Temperature

- Extremely cold temperatures that rarely exceed 40 K



Average temperature of the Haworth crater area in kelvin (K). (Lunar and Planetary Institute, Houston, Texas)

General Science

- Low hydrogen content
- Large areas of crater are permanently shadowed
- The only way this crater has been explored is by orbital imaging radar

Illumination

- Nearly always in permanent shadow; not visible from Earth

Special Considerations

- This crater has a large amount of surface frost.
- The map below shows the slope of various craters, including Haworth.

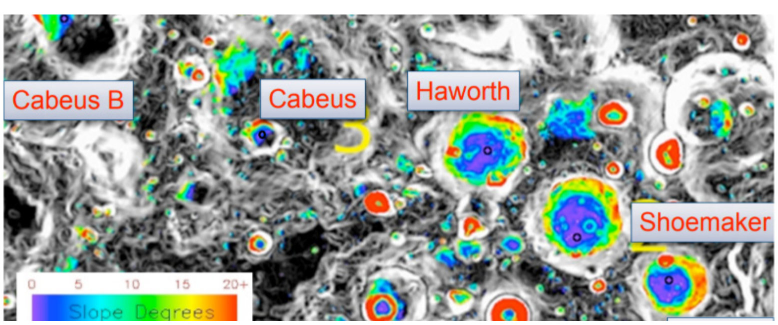
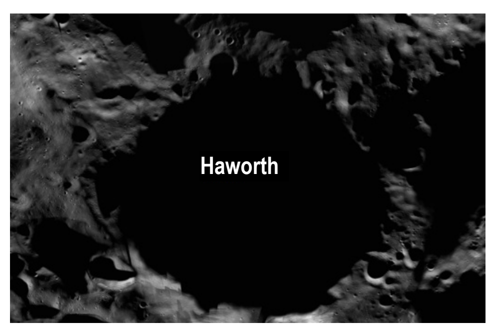


Image showing degrees of slope of Haworth and other craters. (NASA)



Closeup image of Haworth from Moon Trek application. (NASA)

Site Information: Mons Malapert

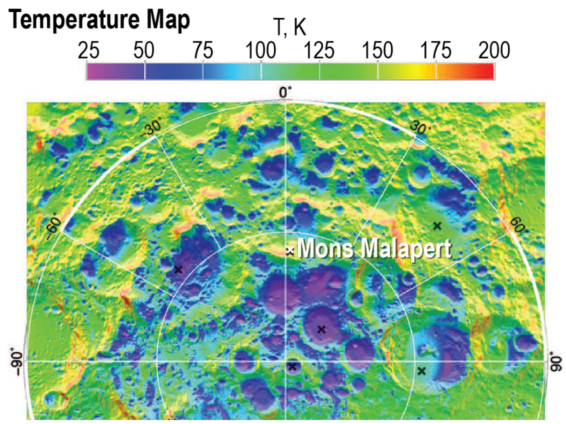
Lunar South Pole visualization using Lunar Reconnaissance Orbiter data. (NASA)

Water and Other Resources

- Enriched iron content
- High hydrogen concentrations

Topography

- A 5-km-high mountain with a long, flat plain at its base
- Slope range is from 6° to 30°



Average temperature (T) for Mons Malapert in kelvin (K). (NASA)

Temperature

- Average temperature is 175 K

General Science

- Located near other permanently shadowed regions
- Located on rim of South Pole–Aitken basin, Moon's largest impact basin (diameter = 2,500 km); several craters in this basin may contain deposits of water ice

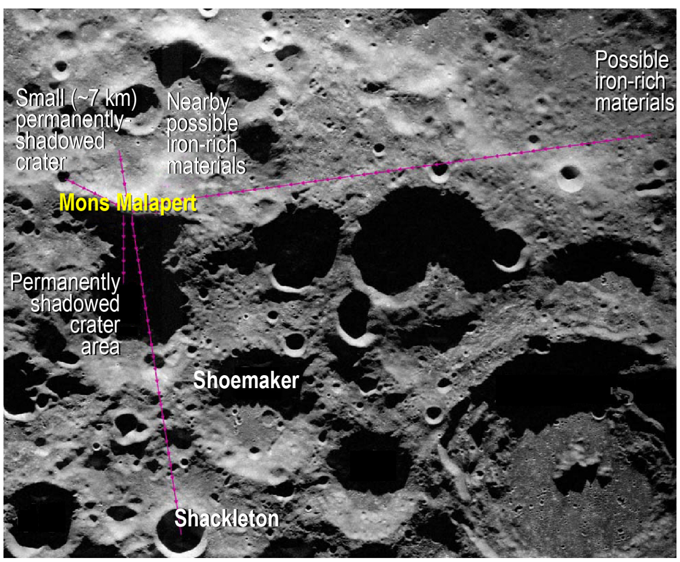


Image of region surrounding Mons Malapert. (NASA)

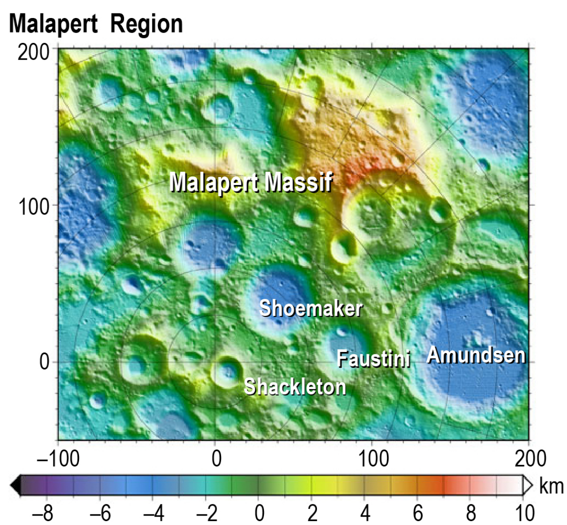


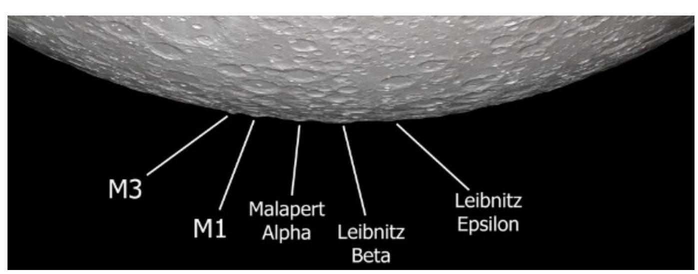
Image depicting elevation of the Malapert region. (NASA)

Illumination

- Receives full or partial sunlight 93 percent of the lunar year

Special Considerations

- Nearby craters like Shackleton
- Mons Malapert can be seen from Earth
- Exceptional visibility of Earth from peak



Five peaks near the lunar South Pole, visible in silhouette. (NASA)

Site Information: Shackleton

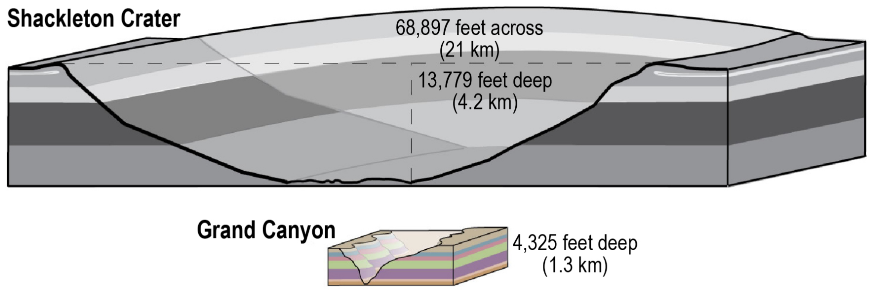
Visualization of Shackleton in natural color. (NASA)

Water and Other Resources

- Floors of the crater are considerably brighter than surrounding craters, indicating small amounts of reflective ice
- Up to 22 percent of the floor may be ice

Topography

- In near darkness most of the year
- Rim of the crater spans 21 km across
- Interior measures over 4 km to the floor and remains in permanent shadow
- Elevated ridges



Shackleton crater versus the Grand Canyon. (Lunar and Planetary Institute, Houston, Texas)

Temperature

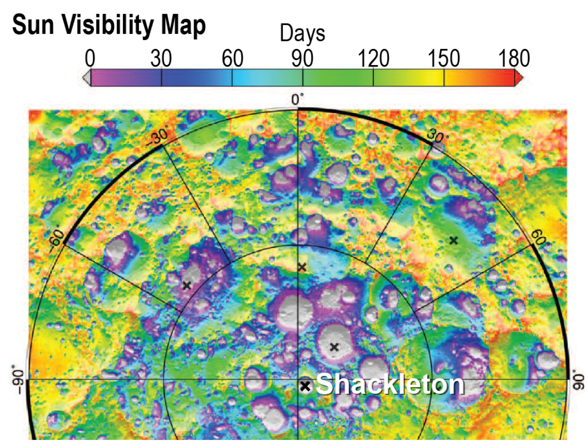
- Relatively high temperatures (80 to 110 K)

General Science

- Explain why the walls of the crater are brighter than the floor.
- The crater is a cold trap that may have collected and stored volatile compounds.

Illumination

- Craters walls are illuminated.
- Rim receives sunlight for half the year.
- Some areas are illuminated 90 percent of the time.
- No areas are permanently illuminated.

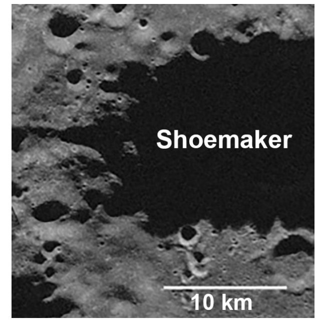


Sun visibility map depicting number of days the Sun is visible for the Shackleton crater. (NASA)

Special Considerations

- Crater walls are too steep for rovers
- Remains relatively unchanged since it was formed 3 billion years ago
- No direct visibility to Earth
- Areas near Shackleton crater are bathed in sunlight

Site Information: Shoemaker



Portion of Shoemaker crater. (NASA)

Water and Other Resources

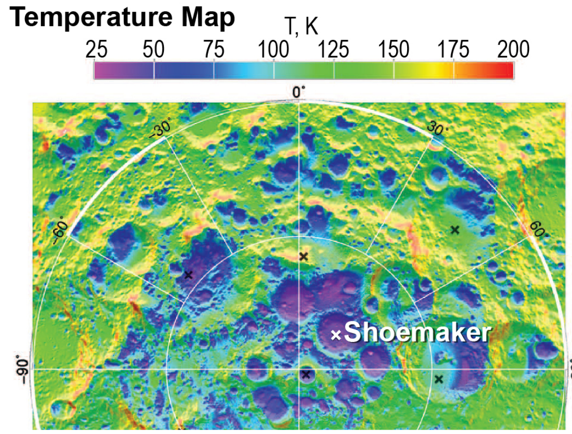
- High abundance of hydrogen
- Water-equivalent hydrogen is 0.15 percent
- Floor of the crater shows no evidence of ice

Topography

- Diameter: 51 km
- Located between Faustini crater and an unnamed crater
- Intact rim with numerous craters
- Highlands terrain

Temperature

- Below 95 K
- Floor forms a cold trap



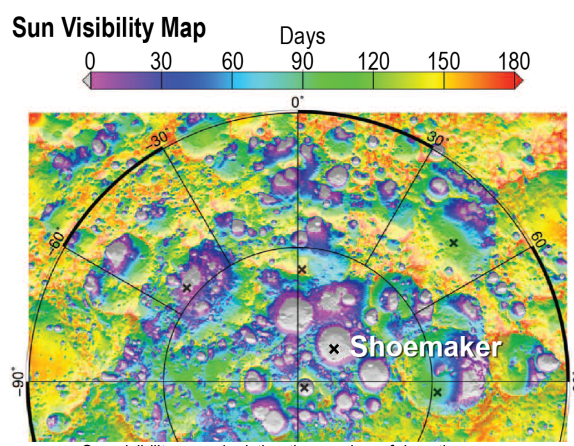
Average temperature (T) for Shoemaker crater in kelvin (K). (NASA)

General Science

- Topographic line of sight to Earth: 0.56 km
- 1999 Lunar Prospector mission crashed into Shoemaker to release trapped water vapor, but none was detected

Illumination

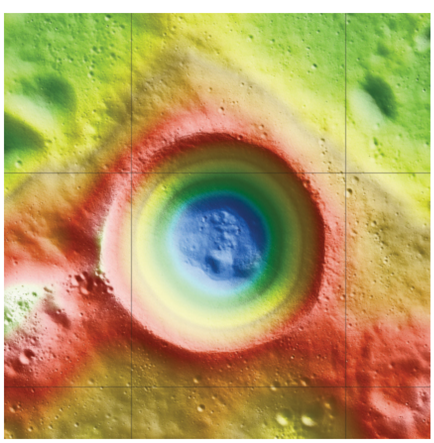
- Floor is kept in total darkness from the Sun
- Shadowed area: 1,175 km^2



Sun visibility map depicting the number of days the Sun is visible for the Shoemaker crater. (NASA)

Special Considerations

- Inner walls highly eroded due to erosion
- Floor of Shoemaker is flat


Elevation map of Shackleton crater with blue indicating lowest area and red/white indicating highest. (NASA/Zuber, M.T. et al.)

Moon Matrix and Temperature Conversions Worksheet

Moon Matrix

Directions: For each landing site, complete the Moon Matrix below. As a team, determine whether the landing site is acceptable (Mission Go), unacceptable (Mission No Go), or cannot be determined based on the information (Need More Data).

	Cabeus	Haworth	Shoemaker	Mons Malapert	Shackleton
Water and Other Resources					
Topography					
***Temperature, °F**					
Illumination					
Science					
Special Considerations					
Mission Go, Mission No Go, or Need More Data					

**You will need to convert the temperatures from kelvin to Fahrenheit using the Temperature Conversions Worksheet below.*

As you examine the Site Information sheets, think about the following questions:

- What benefits might large shadowed regions inside a crater have for an astronaut? Could there be any disadvantages?
- Why would the amount of sunlight an area receives on the Moon be an important factor when determining a good landing site for astronauts?
- Think about the topography of each site. What are the advantages and disadvantages for an astronaut?
- What benefits might a highlands terrain have for an astronaut? Could there be any disadvantages?

Which landing site has your team selected and why?

____

____

____

Temperature Conversions Worksheet

Directions: As you examine temperatures for your landing sites, you will notice that each temperature is in kelvin (K). Convert the temperatures from kelvin to Fahrenheit.

Step 1: Use the conversion equation below to aid you in your conversion.

$$F = (K - 273.14) \times 9/5 + 32$$

Step 2: For each landing site, convert the temperature from kelvin to Fahrenheit.

Landing Site	kelvin, K	Fahrenheit, °F
Cabeus		
Haworth		
Shoemaker		
Mons Malapert		
Shackleton		

Math Extension Worksheet

Directions: If you have picked a landing site that is a crater,* you need to estimate the volume of nearby ice sources using the following equations and information.

Crater	Diameter, km	Surface area occupied by surface water ice, percent	Volume of water ice, km^3
Haworth	51.4	5.4	
Shoemaker	51.8	7.0	
Cabeus	100.6	1.1	
Shackleton	20.9	7.3	
Example Crater	**20**	**3.0**	**0.00942**

* Remember that Mons Malapert is a mountain (massif), not a crater.

Step 1: Using the formula below, find the area of each crater (in km^2) in the table above.

$Area_{crater} = \pi r^2$

Example $Area_{crater}$

Hint: You are given the diameter of the crater, so you must find the radius.

Radius: $r = ½ (20\ km)$
$= 10\ km$

$Area_{crater} = 3.14\ (10\ km)^2$
$= 3.14\ (100\ km^2)$
$= 314\ km^2$

Step 2: Calculate the surface area of ice (in km^2).

$Surface\ Area_{ice}$ = Area of the crater × percentage of surface area occupied by surface water ice

Example Surface $Area_{ice}$

Hint: You must first convert the percentage of surface area occupied by surface water ice into a decimal.

Percentage: 3% = 3/100 = 0.03

$Surface\ Area_{ice} = 314\ km^2 \times 0.03$
$= 9.42\ km^2$

Step 3: Calculate the volume of ice (in km^3).

$Volume_{ice}$ = Surface area of ice × thickness of ice*

*Assume the thickness of ice is a constant of 1 m.

Example $Volume_{ice}$

Hint: You must first convert the thickness of the ice from meters to kilometers.

$Thickness_{ice} = 1\ m \times (1\ km/1{,}000\ m)$ ←unit conversion
$= 0.001\ km$

$Volume_{ice} = 9.42\ km^2 \times 0.001\ km$
$= 0.00942\ km^3$

Optional Exercise

On board the International Space Station, astronauts are limited to 11 liters (L) of water per day. Now that you have calculated an estimate of the volume of ice in the crater, use the conversion below to determine how many days' worth of water your landing site would provide for one astronaut on the Moon.

$$1\ m^3 = 1{,}000\ L$$

Hint: You must first convert your calculations for volume from km^3 to m^3. (1 km^3 = 100,000,000 m^3)

In the example above: 0.00942 km^3 = 9,420,000 m^3 = 9.42 million m^3

Activity Two: Sculpting Lunar Geology

Educator Notes

Learning Objectives

In this activity, students will be designing a scale replica of a portion of the Moon's surface near its South Pole region. Students will compare and contrast the Earth with the Moon and work in cooperative teams to plan their replica. The goal of this activity is to help students consider lunar geology when choosing the optimal site for a human landing system.

Students will use the engineering design process to

- Identify the similarities and differences between the surfaces of the Earth and Moon, with an emphasis on geologic features.
- Create a scale replica of a portion of the surface of the Moon.
- Propose how they could improve their replica given more time and materials.

Investigation Overview

Students are asked to make a scale replica of a portion of the surface of the Moon and label geologic features. If they participated in the previous activity, Choose Your Landing Site, they should make the scale replica of the landing site they chose during that activity. Otherwise, students are free to choose any location near the South Pole region of the Moon, making sure their replica includes at least four geologic features. Students can use the materials of their choice to make their scale replica.

Suggested Pacing

1 to 3 hours

National STEM Standards

Science and Engineering (NGSS)	
Disciplinary Core Ideas • MS-ESS2-2 Earth's Systems: Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales. *Crosscutting Concepts* • Scale, Proportion, and Quantity: Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small. • Stability and Change: Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and processes at different scales, including the atomic scale.	*Science and Engineering Practices* • Analyzing and Interpreting Data: Analyzing data in 6–8 builds on K–5 experiences and progresses to extend quantitative analysis, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. • Developing and Using Models: Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.
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. • Computational Thinker: Students develop and employ strategies for understanding and solving problems in ways that leverage the power of technological methods to develop and test solutions.	*Standards for Students (continued)* • Developing and Using Models: Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • Creative Communicator: Students communicate clearly and express themselves creatively for a variety of purposes using the platforms, tools, styles, formats, and digital media appropriate to their goals.
Mathematics (CCSS)	
Content Standards by Domain • CCSS.MATH.CONTENT.7.RP.A.2.A: Decide whether two quantities are in a proportional relationship, e.g., by testing for equivalent ratios in a table or graphing on a coordinate plane and observing whether the graph is a straight line through the origin. • CCSS.MATH.CONTENT.6.RP.A.1: Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities.	

Activity Preparation

The educator should

- Read the introduction and background information, Educator Notes, and fact sheets to become familiar with the activity.
- Assemble construction materials at one station per team.
- Preload any websites or videos needed for the presentation.
- Print out or provide digital copies of the Landform Fact Sheet, the Landform Identification Worksheet, and images.

Note: Consider collaborating with an art educator on this activity to make it more interdisciplinary.

Materials

- Printouts:
  - Student notebooks or journals
  - Images of Earth and Moon surfaces
  - Photographs of landforms
  - Landform Fact Sheet (provided)
  - Landform Identification Worksheet
- Various modeling materials:
  - Common household materials such as flour, baby powder, or powdered milk
  - Natural materials such as sand, rocks, or pebbles
  - Craft materials such as chalk or modeling clay
- A container for the surface replica (e.g., a 9- by 13-inch baking pan or 11- by 17-inch cookie sheet)
- Newspaper, garbage bags, or dropcloth for the floor

Safety

Use appropriate safety precautions for tool use.

Introduce the Activity

- Inform students that this activity is about the surface of the Moon and that you want to find out how much they already know. Have students write down everything they know about the Moon in approximately 60 seconds, and then compare what is written with the entire group.
  - Tell students that we have been to the Moon and we are going again. Discuss the past Apollo missions. https://www.nasa.gov/mission_pages/apollo/missions/index.html
  - Ask students the following questions:
    - What is the name of the mission that went to the Moon for the very first time?
    - The names of the astronauts?
    - The date?
  - Discuss the Apollo 11 mission. https://www.nasa.gov/mission_pages/apollo/apollo-11.html
- Watch Apollo 11: Landing on the Moon. https://www.youtube.com/watch?v=nOcDftgR5UQ
- Tell students that they will be making a scale replica of a portion of the surface of the Moon and labeling geologic features.

Criteria	Constraints
Replica must be of a location near the Moon's South Pole region.	Replica may not exceed the size of the specified container (e.g., a 9- by 13-inch baking pan or 11- by 17-inch cookie sheet).
Replica must have at least four major geologic features.	
Replica must be built to scale and include a scale legend (e.g., 1 scale centimeter = 100 real kilometers).	

Facilitate the Activity

❓ Ask

- Display the provided picture of the Moon and ask students what they notice about it. Have students hypothesize what the dark and light areas could be and how they got there.
- Ask students to write a short creative narrative or draw a picture that explains their theory about the creation of the Moon. Have them share their narrative or picture with the group.
- Watch the NASA video "Evolution of the Moon." https://www.youtube.com/watch?v=UIKmSQqp8wY.
- Discuss what caused the light and dark areas of the Moon.

Imagine

- Have students imagine it is 4.5 billion years ago. Have them discuss these questions at their team tables:
  - If the Moon is getting hit by meteorites, is the Earth also getting hit?
  - Why (or why not)?
- Have a whole-group discussion, sharing out team thoughts on meteorite impacts.
- Share the images of Earth and Moon surfaces:

- The Earth and the Moon are basically the same age and have experienced a lot of the same things, yet they do not look the same. Have a student-led discussion about why the Earth's and Moon's surface look different. Some possible guiding questions:
  - Why does the Moon have so many more craters than Earth?
    - https://www.nasa.gov/multimedia/imagegallery/image_feature_25.html
    - https://spaceplace.nasa.gov/craters/en/
  - How often does the Moon get struck by meteorites? How often does Earth?
    - https://www.nasa.gov/vision/universe/solarsystem/13jun_lunarsporadic.html
    - https://www.nasa.gov/press-release/goddard/2016/lro-lunar-cratering
  - Does the Moon have volcanoes?
    - https://science.nasa.gov/science-news/science-at-nasa/2014/13oct_moonvolcano
  - Does the Moon have an atmosphere?
    - https://www.lpi.usra.edu/features/100517/moon-atmosphere/
  - Do the Moon and the Earth have the same geologic features?

Brain Booster

An asteroid named 2004 MN4 was once thought to be on a crash course with Earth. The projected date of impact was April 13, 2029. NASA scientists have been watching 2004 MN4 and no longer think it will collide with Earth, although its course changes a little every day. If 2004 MN4 continues as predicted, it will come close to Earth but will not make an impact. It will be closer to us than the Moon is. It will even be closer than our own satellites. 2004 MN4 is a quarter-mile wide and will be visible as it passes. NASA scientists are still tracking it to make sure the course does not change.

Learn more:
https://www.jpl.nasa.gov/news/news.php?feature=7390

On Location

Did you know there is a place where the lunar samples from the Apollo missions are stored? Geologic samples returned from the Moon by the Apollo lunar surface exploration missions (1969 to 1972), along with associated data records, are physically protected, environmentally preserved, and scientifically processed in a special building called the Lunar Sample Laboratory Facility dedicated for that purpose at the Johnson Space Center in Houston, Texas.

Learn more:
https://www.youtube.com/watch?v=7d2qLhrrmi0

Landing Humans on the Moon

The atmosphere and active tectonic plates on Earth have erased most of its craters over the last 4.5 billion years, but the Earth has other geologic features. Some geologic features are shared by Earth and the Moon, and some are unique to each. Have students create a Venn diagram to compare and contrast the features they believe the Earth and the Moon share and the ones that are unique to each. At the end of the lesson, return to the given diagrams and see how many features the students listed correctly and which features are missing.

Plan

- Split students into small teams of no more than four. Provide each team with the student section of this activity (Directions, Landform Identification Sheet, Landform Fact Sheet, and Lunar Landform sheets). Have each team look at the numbered landforms and identify them using the Landform Fact Sheet and the Suggested Student Readings at the end of this section. For additional assistance, they can research each geologic feature on the computer. Students will put an "X" under the corresponding number of the feature on the Landform Identification Sheet.
- After 15 to 20 minutes, bring the teams back together and discuss the landform features. If there are discrepancies in identification, call on teams to explain how they arrived at their answers.
- Discuss:
  - Were some landforms easier to identify than others?
  - What other observations were made?
  - Did shadows help make some landforms easier to see?
- Now that students have identified several types of landforms, return to the discussion of going back to the Moon.
  - When are we going back to the Moon? Watch the video "What Is Artemis?" https://www.youtube.com/watch?v=YOG3tAkPpPE
  - Discuss the Artemis mission and lead the discussion into the geologic features that may exist around the landing site for the mission.
- Explain the project to students. If students did the "Choose Your Landing Site" activity, they have already chosen a location and will now be creating a scale replica of their chosen landing site. If students have not yet done that activity, student teams can choose any location near the lunar South Pole region that contains at least four geologic features.
- Be sure every team member is assigned a student role (see the Teamwork section at the beginning of this guide for recommendations).
- Students can use materials of their choice to create a scale replica of a portion of the Moon's surface and features. Students should be sure to label the landing site and at least four geologic features in their project, leaving one of the labels blank.
- Now that students know what is expected of them, give them time to choose their location, choose the most appropriate materials to replicate the Moon's surface and features, do any other necessary research, and plan out their design.

Create

- After gathering necessary materials, student teams will begin creating scale replicas of their chosen landing site. Students may need time to redesign or adjust if the first attempt does not go as planned.
- Completed projects should have three labeled features and one feature with a blank label. The scale, landing site, and team name should be clearly marked.
- If students are having a problem making the replica to scale, drawing it on graph paper to scale can help in visualizing the site.

Test

- Have students compare their replica to the location it is supposed to replicate. Ask students to reflect using the following questions and have them record their findings in a journal.
  - Does the replica look like the image?
  - Does the replica have all the correct landforms?
  - Is the replica to scale, and is there a legend for the scale?

- What compromises were made because of the limitations of the materials?
- Where on the replica is the best place to land astronauts? Why?

Improve

- From their reflection, have students propose how they could improve their scale replicas given more time and materials.

Share

- Display the replicas and have students perform a gallery walk. Students should identify each person's unlabeled feature. After the gallery walk, discuss the unidentified features.
- Make a display of student projects in a public area.

Extension

- Have students create posters of the features or explanations of the activity to display along with the replicas.
- Use the NASA activity "Blue Marble Matches" to explore the topography of Mars. https://www.nasa.gov/stem-ed-resources/blue-marble-matches.html
- Optional: Share student results on social media using #NextGenSTEM. Be sure to include the module and activity name.

Reference

Field Trip to the Moon
https://www.nasa.gov/pdf/217785main_FTM_Educator_Guide.pdf

Resource

Blue Marble Matches
https://www.nasa.gov/stem-ed-resources/blue-marble-matches.html

Suggested Student Readings

Our Solar System
https://solarsystem.nasa.gov/solar-system/our-solar-system/in-depth/

NASA Planetary Science
https://science.nasa.gov/solar-system

A New Map of the Moon
https://www.nasa.gov/multimedia/imagegallery/image_feature_2110.html

NASA's LRO Creating Unprecedented Topographic Map of Moon
https://www.nasa.gov/mission_pages/LRO/news/lola-topo-map.html

Lunar Rocks and Soils From Apollo Missions
https://curator.jsc.nasa.gov/lunar/index.cfm#

Lunar Regolith
https://curator.jsc.nasa.gov/lunar/letss/regolith.pdf

Activity Two: Sculpting Lunar Geology

Student Handout

Your Investigation

You will be creating a scale replica of a portion of the Moon's surface that could be an ideal human landing site, and you will identify the geologic features in your scale replica.

Criteria	Constraints
Replica must be of a location near the Moon's South Pole region.	Replica may not exceed the size of the specified container (e.g., a 9- by 13-inch baking pan or 11- by 17-inch cookie sheet).
Replica must have at least four major geologic features.	
Replica must be built to scale and include a scale legend (e.g., 1 scale centimeter = 100 real kilometers).	

? Ask

- Observe the picture of the Moon provided. Discuss the characteristics you see and predict what could have caused them.
- Use creative writing or a descriptive drawing explaining where the Moon came from and what it is made up of. Be prepared to share your creations.
- Watch the NASA video "Evolution of the Moon." https://www.youtube.com/watch?v=UIKmSQqp8wY.
- Discuss why the Moon has light and dark areas.

Imagine

- Imagine it is 4.6 billion years ago.
  - If the Moon is getting hit by meteorites, is the Earth also getting hit?
  - Why (or why not)?
- Look at the provided pictures of the Earth and Moon.
- The Earth and the Moon are basically the same age and have experienced a lot of the same things, yet they do not look the same.
- Discuss the following questions with your team. Write down your ideas and be prepared for a whole-group discussion.
  - Why does the Moon have so many more craters than Earth?
  - How often do you think the Moon or Earth gets struck by meteorites?
  - Does the Moon have volcanoes?
  - Does the Moon have an atmosphere?

On Earth, the atmosphere and the movement of tectonic plates have erased most of the craters over the last 4.6 billion years, but that does not mean the Earth does not have geologic features. Some geologic features are shared by the Earth and the Moon, and some are unique to each.

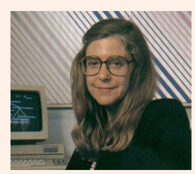
Fun Fact

In 2020, NASA conducted a Lunar Loo Challenge to get involved in solving the age-old issue and very popular question, "How do astronauts go to the bathroom?" NASA's Human Landing System program is looking for a next-generation device that is smaller, more efficient, and capable of working in both microgravity and lunar gravity.

Learn more: https://www.nasa.gov/lunar-loo-challenge

Career Corner

Back in August 1961, before computers were part of everyday life, Margaret Hamilton and her team developed the building blocks of software engineering. Hamilton led the Software Engineering Division of the Massachusetts Institute of Technology (MIT) Instrumentation Laboratory that developed the guidance and navigation system for the Apollo spacecraft.



Margaret Hamilton

NASA honored Hamilton in 2003 with a special award recognizing the value of her innovations in the Apollo software development. In 2016, President Barack Obama awarded her the Presidential Medal of Freedom.

Learn more: https://www.nasa.gov/feature/margaret-hamilton-apollo-software-engineer-awarded-presidential-medal-of-freedom

Plan

Working in a team, you will be given eight Lunar Landform sheets that show geologic features of the Moon. The features are numbered on the photographs and you will need to identify them and record your findings on the Landform Identification Sheet. You may use the Landform Fact Sheet, Suggested Student Readings, and the internet to assist you. When completed, be ready to defend all answers.

Next, the team will work to create a scale replica of a portion of the Moon.

- Choose the area that you will replicate. If you completed the activity "Choose Your Landing Site," use the chosen landing site for this activity. If you did not do that activity, choose a location near the lunar South Pole region.
  - The location should have at least four different major geologic features.
  - Label three of the four major geologic features. The fourth label should be left blank for a later activity.
  - The replica should be in a container.
  - Determine which materials the team will be using to represent the lunar surface.
  - Be sure that each person in the team has a role or job in the project.
  - A sketch or plan of the replica should be turned in with the final project.
- Have your image available for reference when creating your replica.
- Research as needed for location, elevation, and surface features:
  - Lunar South Pole Atlas
    - https://www.lpi.usra.edu/lunar/lunar-south-pole-atlas/
  - Elevation
    - https://www.nasa.gov/exploration/multimedia/highlights/2010-09B.html
    - https://www.nasa.gov/multimedia/imagegallery/image_feature_2110.html
  - Lunar regolith
    - https://curator.jsc.nasa.gov/lunar/index.cfm#
    - https://curator.jsc.nasa.gov/lunar/letss/regolith.pdf

Create

- Create your lunar replica. If it is not working as planned, do not be afraid to redesign and start again with the materials at hand, using the time that you have left. Be sure to label three of the four features and leave the fourth feature blank. Make sure the team's name is visible on the project.

Test

- Once your replica is complete, discuss these questions with the team:
  - Does the replica look like the image?
  - Does the replica have all the correct landforms labeled?
  - Is the replica to scale, and is there a legend for the scale?
  - What compromises did your team make because of material limitations?
  - Where on the replica might be a good place to land astronauts?

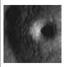
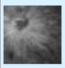
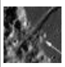
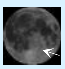
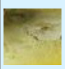
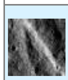
Improve

- From your reflection, propose how you would improve your scale replicas if you had more time and materials.

Share

- Go around to each team's replica. In your journal, write the name of the team and what the unidentified feature is.

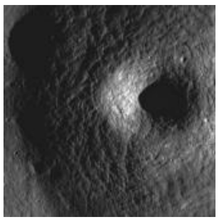
Landform Identification Sheet

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
 Central Crater Uplift																				
 Cinder Cone																				
 Crater Ejecta																				
 Dome																				
 Highlands																				
 Impact Crater																				
 Lava Flow																				
 Maria																				
 Multi-Ringed Basin																				
 Ray																				
 Rille																				
 Terraced Crater Walls																				
 Wrinkle Ridge																				

Landform Fact Sheet

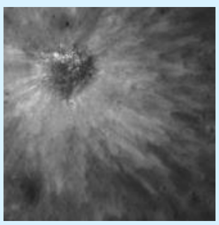
Central Crater Uplift

Mountain in the center of large (greater than 40 kilometers in diameter) impact craters



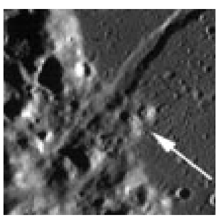
Cinder Cone

A low, broad, dark, cone-shaped hill formed by an explosive volcanic eruption



Crater Ejecta

Material thrown out from and deposited around an impact crater



Dome

A low, circular, rounded hill that is suspected to be a volcanic landform

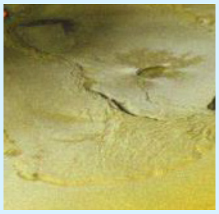
Highlands

Bright-appearing areas composed of countless overlapping craters (ranging from 1 meter to over 1,000 meters) that formed when meteorites crashed into the Moon

Impact Crater

A roughly circular hole created when something, such as a meteorite, struck the Moon's surface

Landform Fact Sheet



Lava Flow

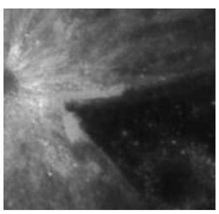
A breakout of magma from underground onto the surface

Maria

Areas that formed when lava flows filled in low places. The low places are mostly inside huge basins that were formed by large meteor impacts. The maria cover 16 percent of the Moon's surface.

Multi-Ringed Basin

Huge impact crater surrounded by circular mountain chains



Ray

Bright streak of material blasted out from an impact crater

Rille

A channel in the lunar maria formed by an open lava channel or a collapsed lava tube

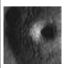
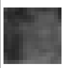
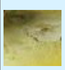
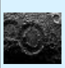
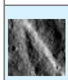
Terraced Crater Walls

Steep walls of an impact crater with "stair steps" created by slumping due to gravity and landslides

Wrinkle Ridge

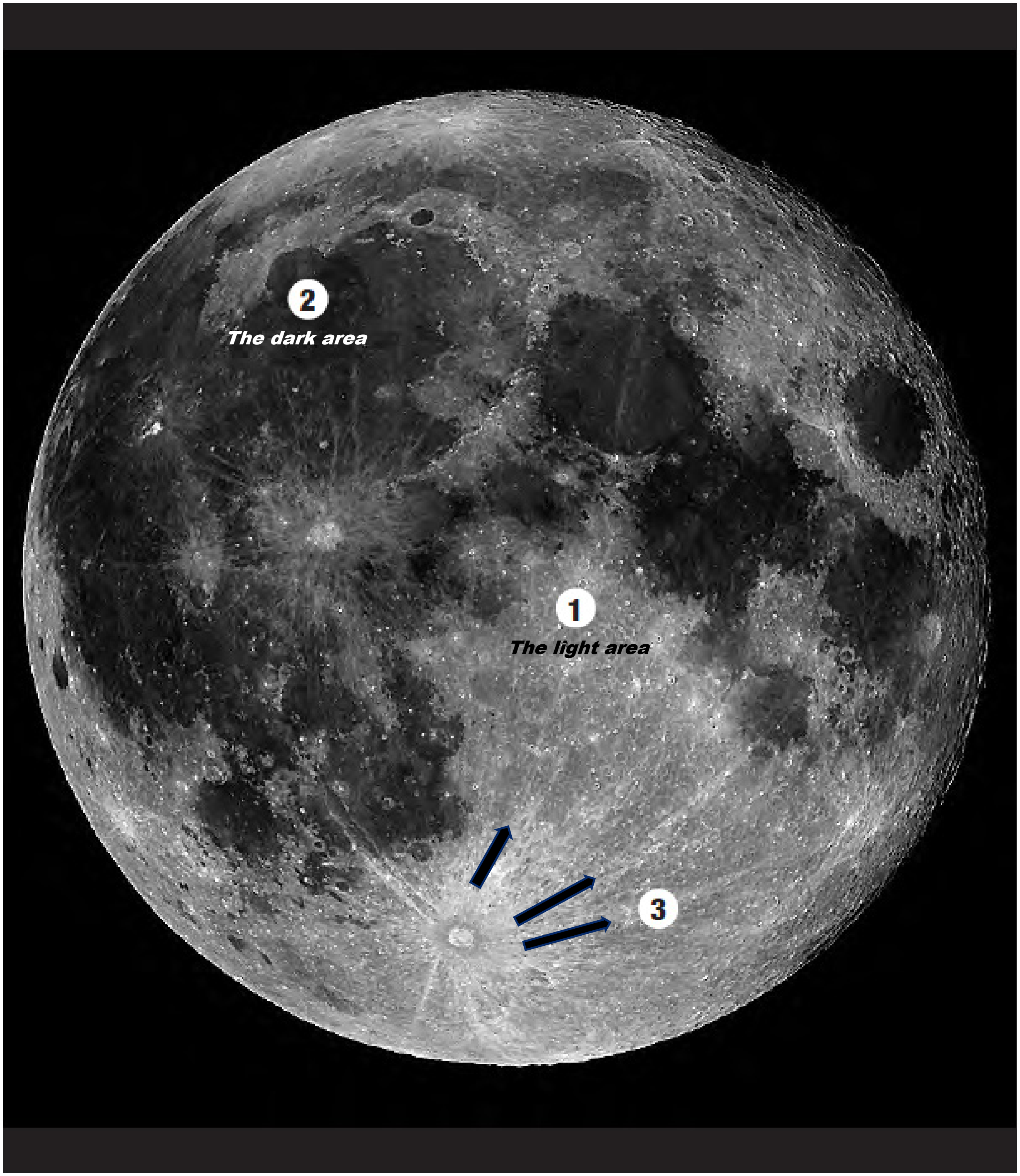
A long, narrow, wrinkly, hilly section in the maria

Landform Identification Sheet Answer Key

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
 Central Crater Uplift													X							X
 Cinder Cone										X										
 Crater Ejecta											X									
 Dome																X				
 Highlands	X				X															
 Impact Crater								X	X											
 Lava Flow														X						
 Maria		X				X														
 Multi-Ringed Basin				X																
 Ray			X															X		
 Rille							X										X			
 Terraced Crater Walls												X						X		
 Wrinkle Ridge															X					

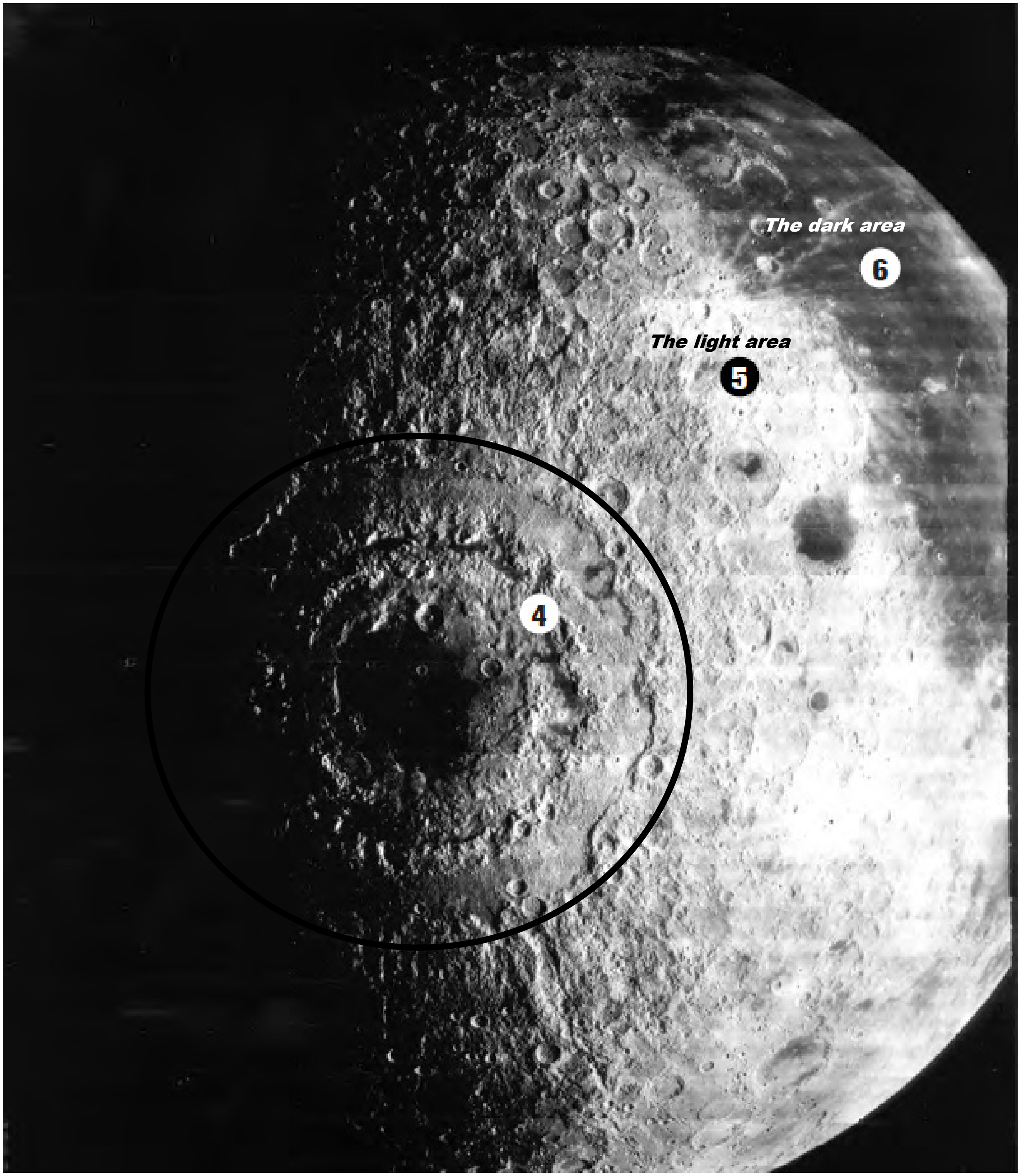
Lunar Landforms: Sheet 1

The Moon



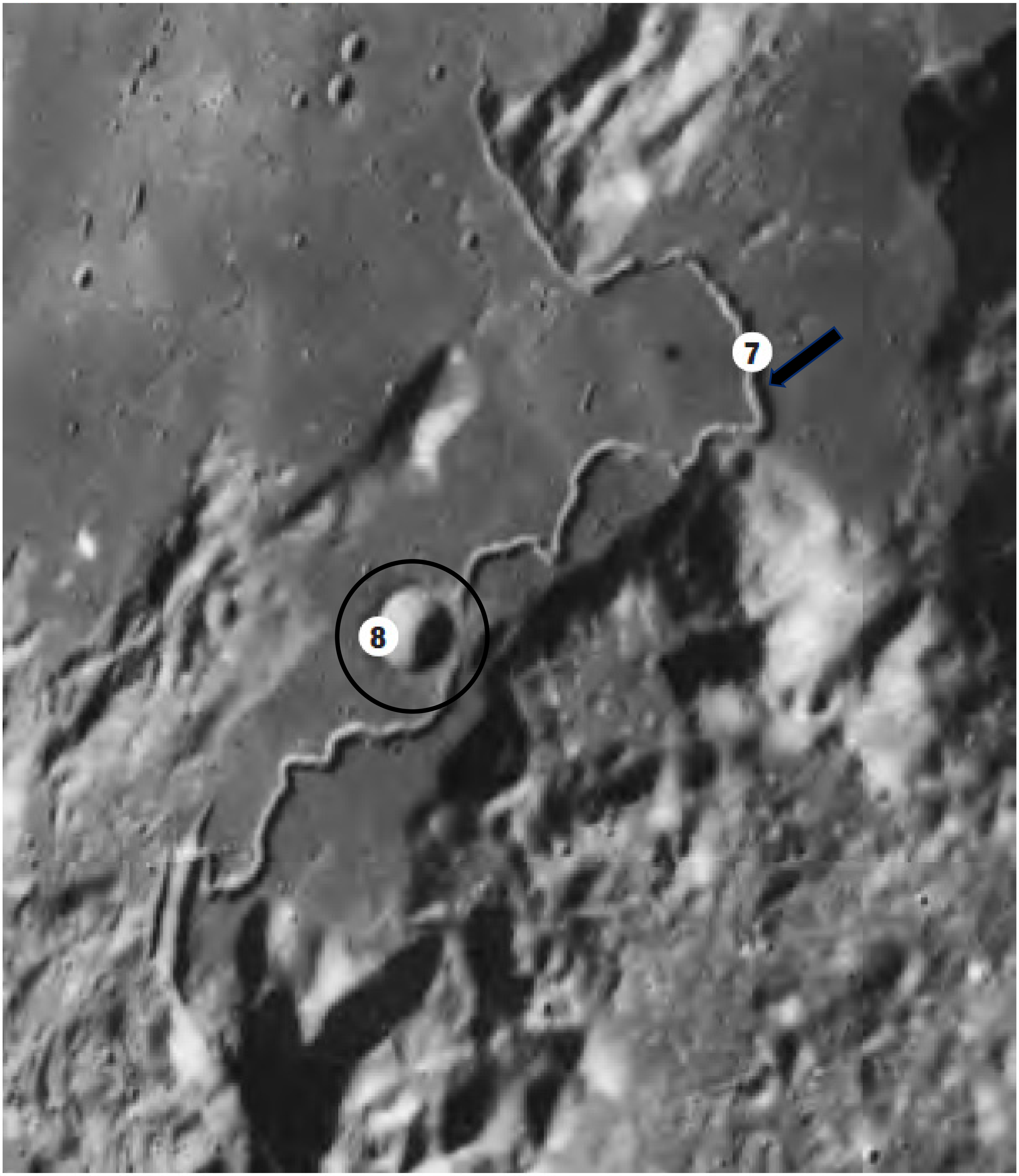
Lunar Landforms: Sheet 2

Orientale



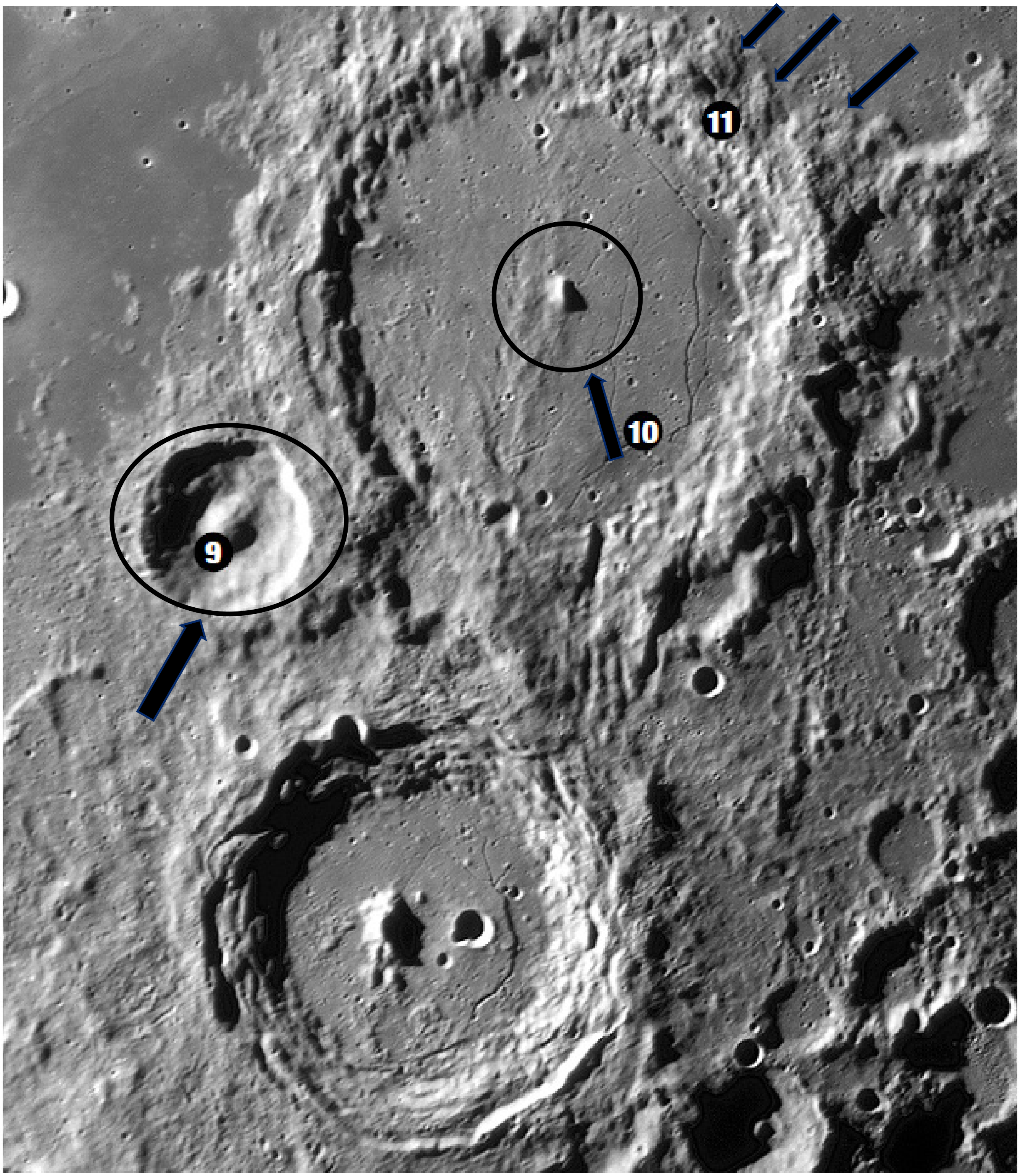
Lunar Landforms: Sheet 3

Apollo 15 Landing Site



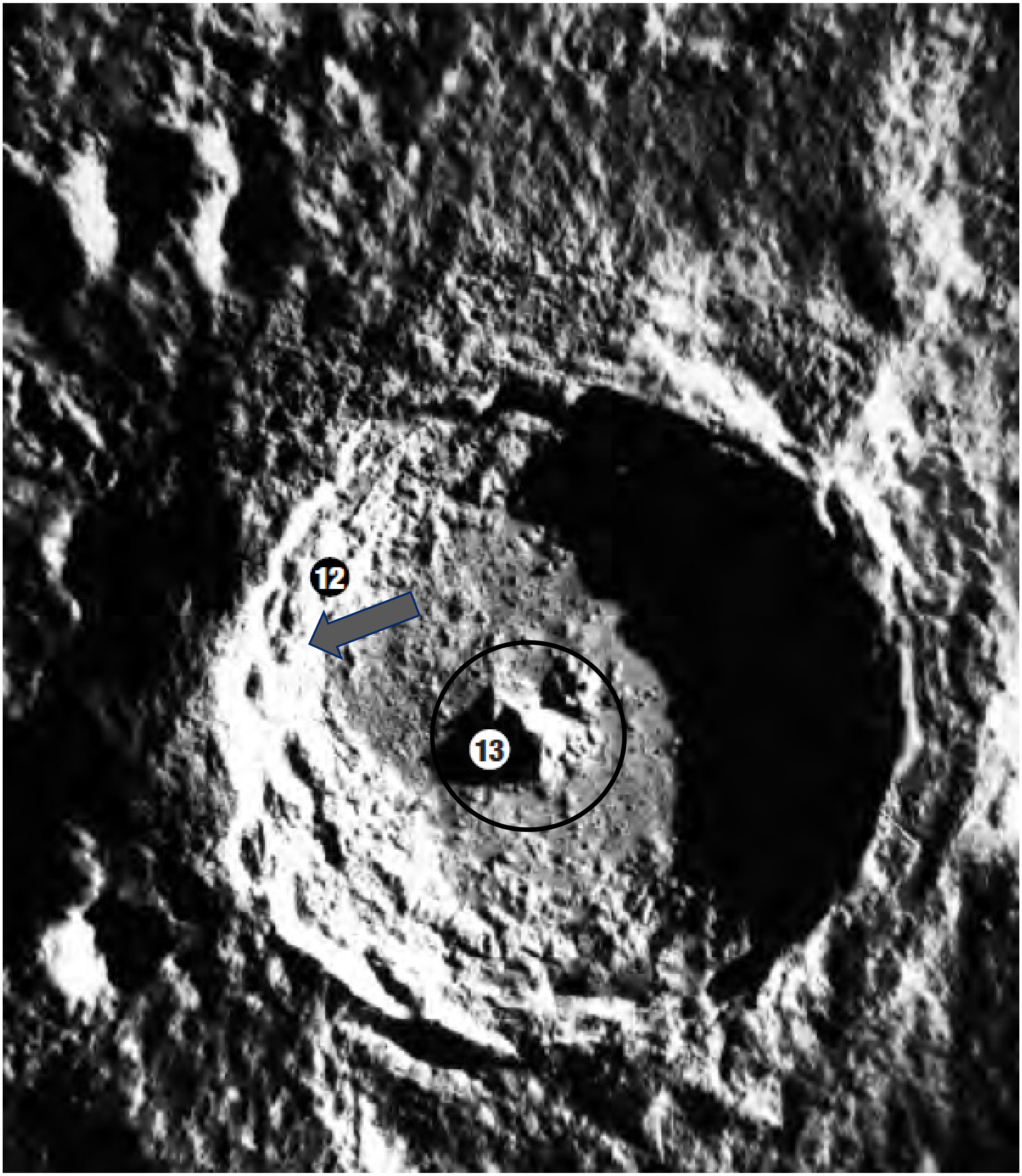
Lunar Landforms: Sheet 4

Alphonsus



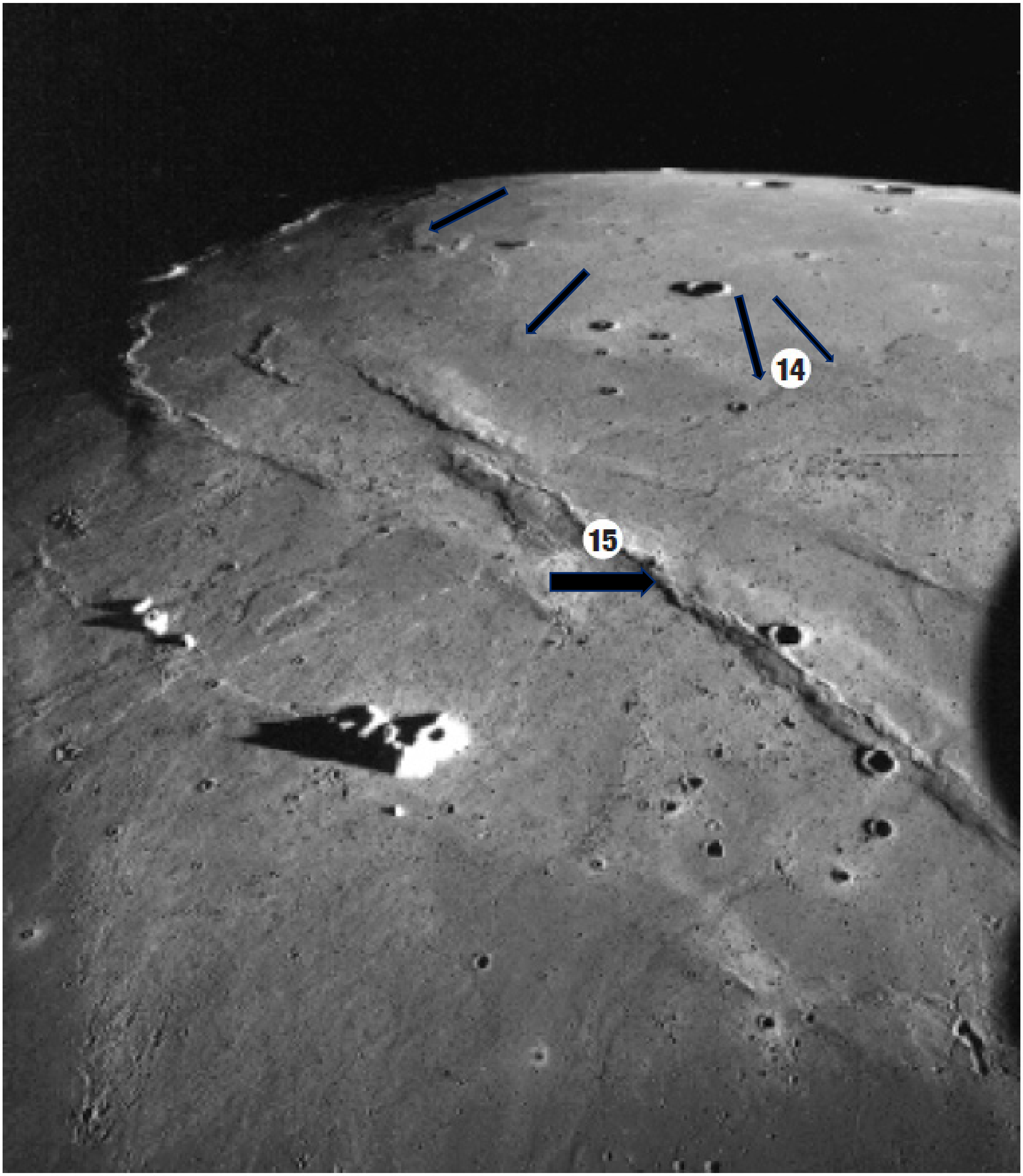
Lunar Landforms: Sheet 5

Tycho



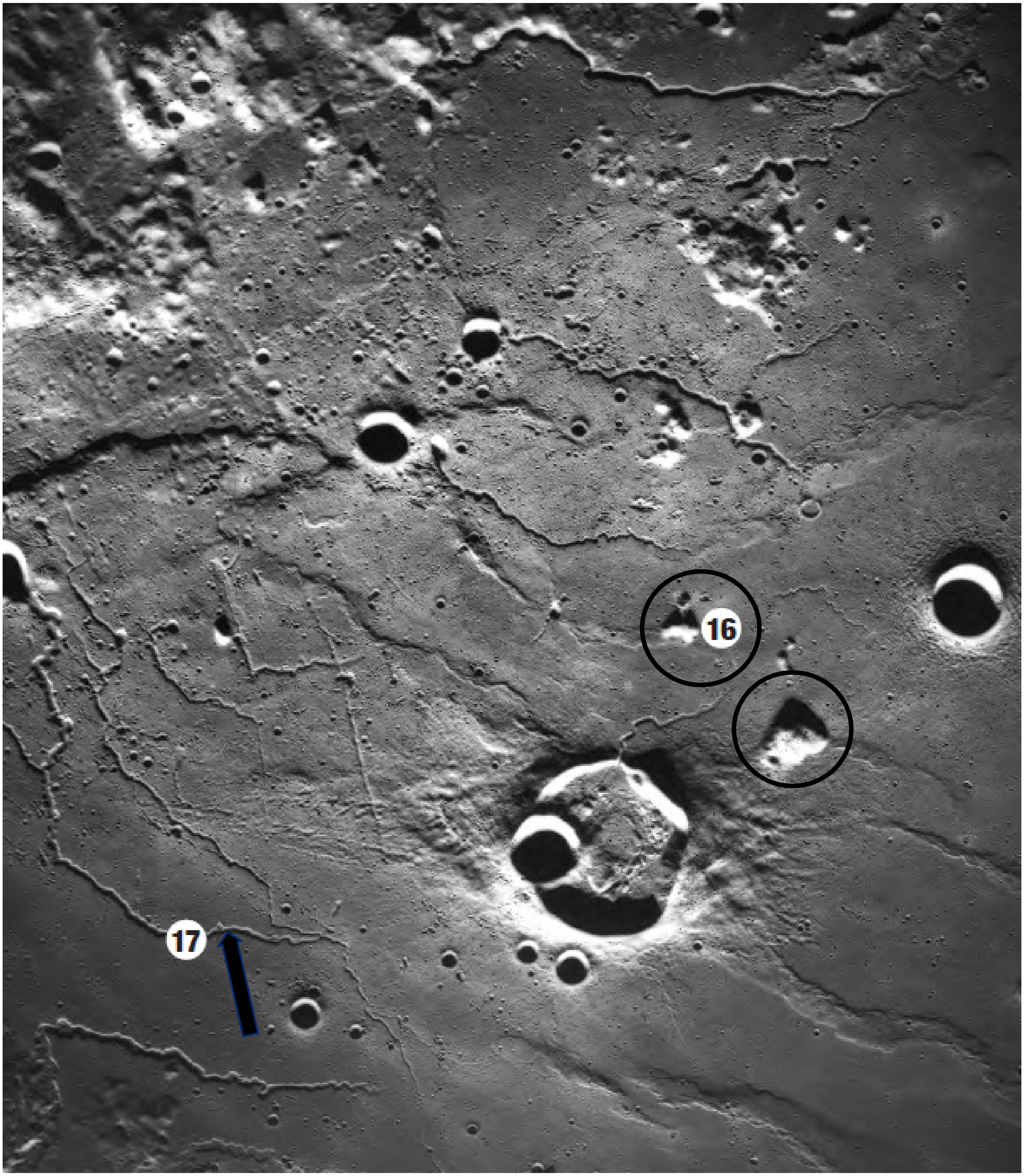
Lunar Landforms: Sheet 6

Mare Imbrium



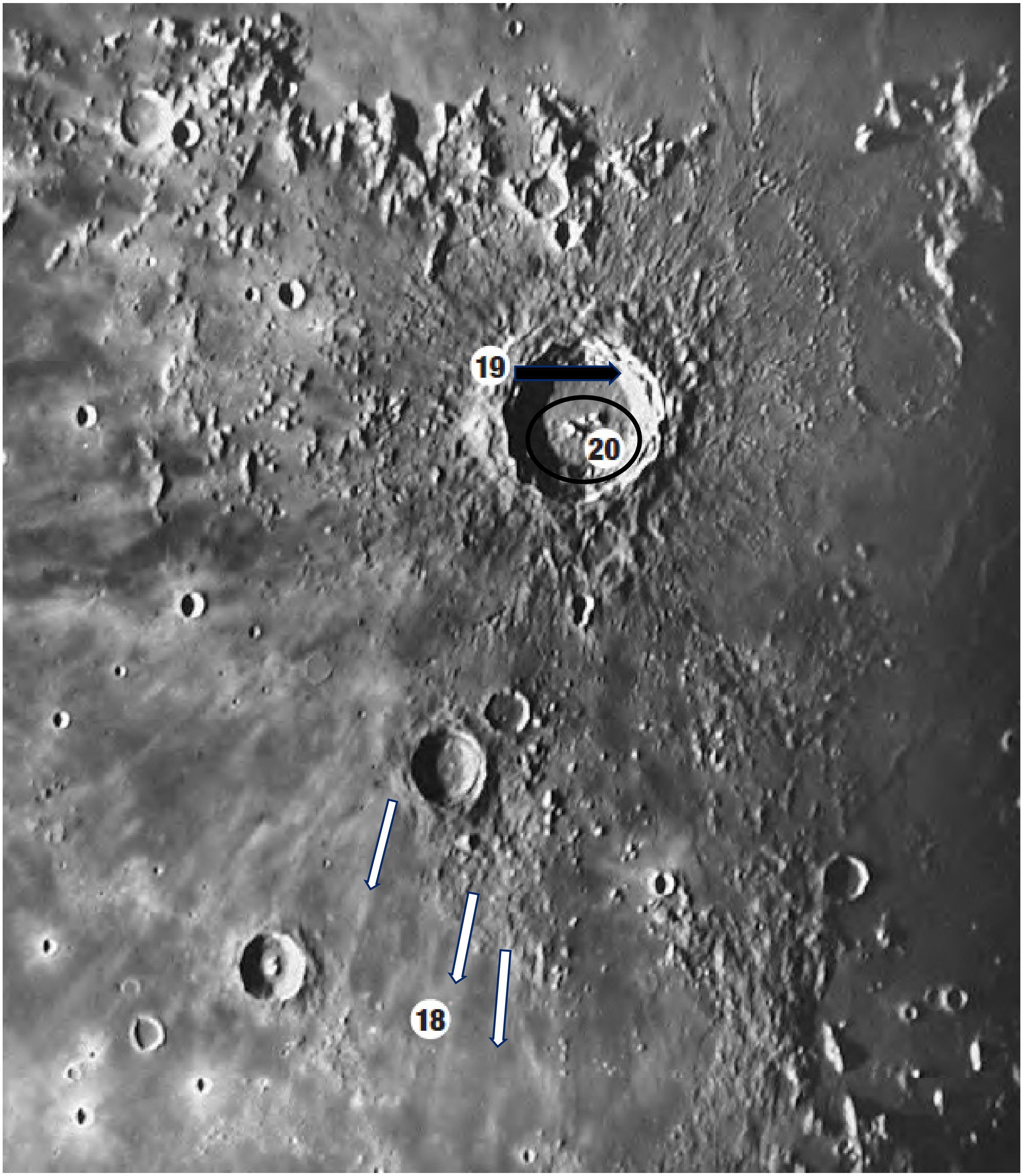
Lunar Landforms: Sheet 7

Ocean of Storms



Lunar Landforms: Sheet 8

Copernicus



Activity Three: Priority Packing for the Moon

Educator Notes

In this activity students will be conducting a simulated mission to the Moon. Students will expand their knowledge about basic human needs by thinking about what resources will be necessary on a mission to the Moon. Students will identify resources available at their selected landing site and what science missions should be conducted. Students will also need to prioritize what to pack for living and working at their selected Moon site.

Learning Objectives

Students will use the engineering design process to

- Evaluate the importance of given objects based on basic human needs and availability of space on a lander in order to be successful on a mission to the Moon.
- Optimize a given volume for packing items for space in the human landing system cargo bay.

Challenge Overview

Students will engage in a Moon survival scenario, select a Moon science mission based on a chosen landing site, prioritize the items for the mission, and describe how to optimize a packing solution.

Suggested Pacing

45 to 90 minutes

National STEM Standards

Science and Engineering (NGSS)	
Disciplinary Core Ideas • MS-LS2-1 Ecosystems: Interactions, Energy, and Dynamics: Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem. *Crosscutting Concepts* • Scale, Proportion, and Quantity: In considering phenomena, it is critical to recognize what is relevant at different size, time, and energy scales, and to recognize proportional relationships between quantities as scales change. • Stability and Change: For both designed and natural systems, conditions that affect stability and factors that control rates of change are critical elements to consider and understand. *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.	*Science and Engineering Practices (continued)* • 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. • Engaging in Argument From Evidence: Argumentation is the process by which explanations and solutions are reached. • Obtaining, Evaluating, and Communicating Information: Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical professional activity.
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. • Computational Thinker: Students develop and employ strategies for understanding and solving problems in ways that leverage the power of technological methods to develop and test solutions.	*Standards for Students (continued)* • Creative Communicator: Students communicate clearly and express themselves creatively for a variety of purposes using the platforms, tools, styles, formats, and digital media appropriate to their goals.
Mathematics (CCSS)	
Content Standards by Domain • CCSS.MATH. CONTENT.7.G.B.6: Solve real-world and mathematical problems involving area, volume, and surface area of two- and three-dimensional objects composed of triangles, quadrilaterals, polygons, cubes, and right prisms. • CCSS.MATH.CONTENT.6.G.A.2: Find the volume of a right rectangular prism with fractional edge lengths by packing it with unit cubes of the appropriate unit fraction edge lengths, and show that the volume is the same as would be found by multiplying	the edge lengths of the prism. Apply the formulas $V = l\ w\ h$ and $V = b\ h$ to find volumes of right rectangular prisms with fractional edge lengths in the context of solving real-world and mathematical problems. • CCSS.MATH.CONTENT.6.G.A.4: Represent three-dimensional figures using nets made up of rectangles and triangles and use the nets to find the surface area of these figures. Apply these techniques in the context of solving real-world and mathematical problems.

Activity Preparation

The educator should

- Read the introduction and background information and the Educator Notes to become familiar with the challenge.
- Determine teams and roles ahead of time (see the background information at the beginning of this guide for recommendations).
- Print the following:
  - Student Handout (one per student)
  - Lunar Cargo Packing List (one per team) Lunar Cargo Polyominoes sheets (one of each kind per team)

    Note: Polyominoes are equal-sized squares joined together edge to edge to form a plane geometric figure.
- Provide computer access to students so they can visit NASA Moon to Mars resources.

Materials

- Printouts
- Lunar Map from Activity 1 (Choose Your Landing Site)
- Poster paper
- Writing utensil
- Glue or tape
- Scissors
- Computers for site research OR print out the five Site Information sheets from Activity 1 (Choose Your Landing Site)

Safety

Practice safety protocols for scissor use.

Introduce the Challenge

- Inform students that they will be working in teams to prioritize and pack for a science mission to the Moon.
- Remind students that the landing site they select (or are assigned) will determine what they will be packing for survival and for their science investigation.

Criteria	Constraints
You must maximize space available for packing. (10 × 10 square = 100 units)	You may not exceed the space provided. (10 × 10 square = 100 units)
You must include life support resources (unless found at your site) and science equipment for your mission in your payload. (Note: See Brain Booster for 1-day uses for the average human.)	You may not leave out anything from your priority list: food, supplies, life support, science equipment, power equipment, and building equipment.
You must have enough basic life support for 7 days on the Moon for each team member astronaut.	You may not assume there are resources at your landing site if they have not been researched.
Your final packing solution must reflect the predetermined priority list and maximize your packing area but may be under 100 percent.	Your final packing solution may not go over 100 percent.

Facilitate the Challenge

Ask

NASA plans on going back to the Moon and will demonstrate how humans will be able to live sustainably on the South Pole region of the Moon. The human landing system will deliver the astronauts to the surface of the Moon at a predetermined site where they can live and work for up to 7 days and conduct specific science missions.

Look at the map of the lunar South Pole region, with the five predetermined landing sites. Assign teams to a specific landing site and provide them with the corresponding Site Information sheet from Activity One. Ask students to think about what they know about the basic needs of humans. What resources will astronauts need to bring with them, and what science investigations can be conducted?

- What are the basic things that organisms need to live?
- How is being on the Moon different than being on Earth?
- What would astronauts living on the Moon need for survival?
- What supplies will you take for your science mission based on the assigned location?
- How can you prioritize and pack supplies in the cargo bay following design criteria?

Imagine

Survival Scenario (read to students):

> The year is 2025 and you are part of a four-member team traveling toward the Moon. As your spacecraft enters lunar orbit, you spot the base camp. It is located on a crater rim near the lunar South Pole, in near-constant sunlight. This location is not far from supplies of water ice that can be found in the cold, permanently shadowed part of the crater. As your spacecraft descends toward the lunar surface, you suddenly notice that there is a problem with the thrusters. You land safely, but off course, about 25 kilometers (approximately 15 miles) from the base camp. As you look across the charcoal-gray, dusty surface of the Moon, you realize your survival depends on reaching the base camp, finding a way to protect yourself until someone can reach your team, or meeting a rescue party somewhere between your landing site and the habitat. You know the Moon has basically no atmosphere or magnetosphere to protect you from space radiation. The environment is unlike any found on Earth. The regolith, or lunar soil, is a mixture of materials that includes sharp, glassy particles. The gravity field on the Moon is only one-sixth as strong as Earth's. More than 80 percent of the Moon is made up of heavily cratered highlands. Temperatures vary widely on the Moon. It can be as cold as 193 °C (–315 °F) at night at its poles and as hot as 111 °C (232 °F) during the day at its equator. Survival will depend on your mode of transportation and your ability to navigate. Your basic needs for food, shelter, water, and air must be considered. With the Moon's lower gravity, 25 kilometers (approximately 15 miles) is not too far to walk, but you are limited in what you can carry. You can only take seven items with you. What should you take with you and why?
>
> Of the 12 items available, strategize with your team and prioritize the 7 items your team will carry during your journey to the lunar base camp. Your survival depends on your ability to work with other team members to determine not only the value of these items, but how to use them as well.
>
> 1. Box of matches
> 2. Oxygen
> 3. Food
> 4. Water
> 5. Lights with solar-powered rechargeable batteries
> 6. Magnetic compass
> 7. Solar powered receiver–transmitter
> 8. Life raft
> 9. First aid kit

Share With Students

Brain Booster

On Earth, the average American uses about 132 liters (roughly equal to 35 gallons) of water every day. In contrast, the average astronaut on the International Space Station (ISS) uses 11 liters (3 gallons) of water. Water is heavy (1 kilogram per liter), so attempts are made to minimize the amount of water carried on board a spacecraft. An astronaut on the ISS uses about 0.83 kilograms (1.83 pounds) of food per meal each day. The average person (both on the ISS and on Earth) needs about 0.84 kilograms of oxygen per day.

Learn more:
https://www.nasa.gov/content/life-support-systems

On Location

NASA's Planetary Missions Program Office, which is located at Marshall Space Flight Center, helps humanity answer profound questions about the nature of the solar system and our place in it. On a certain night of the year, this office hosts an International Observe the Moon Night. This is a worldwide event that encourages observation, appreciation, and understanding of our Moon and its connection to NASA exploration and discovery.

Check out the website to participate in a town near you:
https://moon.nasa.gov/observe-the-moon-night/about/overview/

10. Map of Moon's surface
11. 15 meters (approximately 50 feet) of nylon rope
12. Signal mirror

Once the teams have agreed on their seven essential items, facilitate a whole-team discussion on the reasoning behind each student's choices. Be open to all answers if students have reasonable justifications for their order and reasoning. This activity helps to verify students' understanding of the conditions on the Moon. This can also lead to identifying student misconceptions about the Moon's environment. (Winning student/team has the most points for correct order; see the following priority table and scoring information.)

NASA's Suggested Priority Items

Item	Priority Level	Explanation
Oxygen	High	Oxygen to breathe is the most important survival need, since the Moon has virtually no atmosphere.
Water	High	Water is another basic survival need for the astronauts. Because there is no liquid water on the Moon, the astronauts will need the water they brought with them to survive.
Food	High	Although the food concentrate must have water added to be useful, it is lightweight and easy to carry, meeting a third basic need for survival.
Solar-powered receiver–transmitter	High	As people from the lunar outpost are looking for you, you should try to reach them. Maintaining communication with your outpost is essential.
First aid kit	High	A first aid kit takes up little space and may be important to have in case of illness or injury.
Map of Moon's surface	High	With no other directional tools available, a map of the Moon's surface is necessary.
Life raft	Medium	The life raft makes a great sled for carrying the oxygen and water.
15 meters (about 50 feet) of nylon rope	Medium	The rope makes dragging the life raft easier or may come in handy when crossing difficult terrain.
Lights with solar-powered rechargeable batteries	Medium	The lights are helpful if you travel across large shadowed areas. Some areas in the polar regions are permanently dark.
Signal mirror	Medium	The signal mirror is used as a form of communication if the radio is not working.
Box of matches	Low	With little oxygen on the Moon, the matches are useless.
Magnetic compass	Low	The compass is virtually useless because there is no Moon-wide magnetic field.

Scoring

For each of the student/teams' seven items, add the number of points (3 – High Priority, 2 – Medium Priority, 1 – Low Priority) from the NASA ranking, then add up all the points.

- 20 or more: Excellent – Future Moon Explorers!
- 19: Good
- 18: Average
- 17: Poor – Suggests use of Earthbound logic
- 16 or fewer: Very poor – Need to go back to Basic Astronaut Moon Survival Training!

Plan

- Take out the Lunar Cargo Packing List. Have student teams prioritize six items for a mission to their landing site. This is the first step to prioritize the cargo they will bring to the Moon.

- Have each team draw a 10- by 10-inch square on a large sheet of paper. This space represents the (500-kilogram-unit) cargo bay of their human landing system, which will transport the basic needs and science cargo for the mission. Have each team cut out the six sets of shapes on the Lunar Cargo Polyominoes worksheets. Polyominoes are equal-sized squares joined together edge to edge to form a plane geometric figure.
- These shapes represent cargo that needs to be packed into the human landing system. The percentage shown on each item represents the *percentage of volume* it will occupy in the cargo bay.

Create

- Based on their team's original priority list, students will fit the shapes in the cargo bay, beginning with the supplies they will need the most of. For example, if food is their number one priority, there should be a greater *percentage* of food packed in the cargo bay.
- Teams should try to pack the cargo so there are no empty spaces. Be sure students use only the shapes given and do not cut them to make them fit in the cargo bay.

Test

- Have students follow the second step on the Lunar Cargo Packing List worksheet to calculate the percentages of each type of packed cargo. A fully packed cargo bay will equal 100 percent.
- Have students compare their final decision with their original priority list.

Improve

- If necessary, instruct students to repack the cargo bay until the priority list has been followed and space has been used to its maximum capacity.

Share

Engage students with the following discussion questions:

- What are the advantages and disadvantages of your team's site?
- What resources are available to the astronauts at your landing site?
- Did you obey all the criteria and constraints in this activity?
- Think about how density, mass, and balance can affect human spaceflight. How could your team pack the payload based on density, mass, and balance? Discuss various packing solutions.
- Does your final packing decision reflect your original priority list?
- Do you have enough evidence that NASA would agree with the priority packing your team has chosen?

Note: Depending on the time remaining, teams can also present their final packed cargo bay and the reasons they chose the cargo they did, based on the science mission and landing site the team selected or was assigned. Remember, there is not a "perfect" answer if teams can justify and defend their final packing solution. There are a variety of ways that student teams can present their findings and conclusions. Suggestions for presentations include a Q&A session, a Moon Realty presentation, or a team presentation using jigsaw.

Have students justify their packing plans:

- Defend your choices in the items your team picked.
- What is a "high-priority" item and what determines it being a high priority?
- Why did you not select certain items?
- Did your final packing solution match your priority list?

Optional: Share student results on social media using #NextGenSTEM. Be sure to include the module and activity name.

Extensions

- Provide printed directions to help students who may need additional structure for the inquiry.
- Educators can make this activity more realistic and switch from 2D to 3D by using polyominoes, a math manipulative. Another 3D option would be to have students fill a shoebox with "cargo" items, like building blocks of various sizes.
- Allow students to "dive deeper" into the science missions. Refer to NASA web links and information provided in the background section.

Pick Your Science Mission (Extension Activity)

- Student teams decide on a mission for a particular location and identify items needed for that science mission. If jigsaw grouping is being used, have the Activity One expert choose the location. If not, have teams randomly select a site on the South Pole from Activity One.
  - If you had complete control, what would you place in your lander for your mission? Justify your decision. Do not forget basic Moon survival needs (food, water, and shelter with an energy source).
  - Research what actual scientists would be doing and their science equipment needs.
- Moon Mission Objectives:
  - Study of planetary processes
  - Understanding volatile cycles
  - Interpreting the impact history of the Earth–Moon system
  - Revealing the record of the ancient Sun
  - Observing the universe from a unique location
  - Conducting experimental science in the lunar environment
  - Investigating and mitigating exploration risks to humans
- Allow students to make a new priority packing list for packing specific science equipment based a new landing site.

References

Field Trip to the Moon
https://www.nasa.gov/pdf/305948main_FTM_LRO_Informal_Guide.pdf

Survival! Exploration: Then and Now
https://www.nasa.gov/pdf/166504main_Survival.pdf

Resources

NASA Trek Link (Moon Map)
https://trek.nasa.gov/moon/#v=0.1&x=0&y=0&z=1&p=urn%3Aogc%3Adef%3Acrs%3AEPSG%3A%3A104903&d=&locale=&b=moon&e=-224.99999580294752%2C-106.52343551295796%2C224.99999580294752%2C106.52343551295796

Explore Space Exploration: Build a Moon Base
https://www.lpi.usra.edu/education/explore/beyondEarth/activities/buildAcolony.shtml

Activity Three: Priority Packing for the Moon

Student Handout

Your Challenge

You will be assigned a landing site on the South Pole of the Moon using NASA topographic maps and data. You will engage in a Moon survival scenario, prioritize items for a Moon mission, and describe how to optimize a packing solution for all your supplies.

Criteria	Constraints
You must maximize space available for packing. (10 × 10 square = 100 units)	You may not exceed the space provided. (10 × 10 square = 100 units)
You must include life support resources (unless found at your site) and science equipment for your mission in your payload. (Note: Research necessary here to identify the average 1-day uses for the average human.)	You may not leave out anything from your priority list: food, supplies, life support, science equipment, power equipment, and building equipment.
You must have enough basic life support for 7 days on the Moon for each team member astronaut.	You may not assume there are resources at your landing site if they have not been researched.
Your final packing solution must reflect the predetermined priority list and maximize your packing area but may be under 100 percent.	Your final packing solution may not go over 100 percent.

? Ask

NASA has a mission to explore the South Pole region of the Moon.

- What would astronauts living on the Moon need to survive?
- What supplies will you take for your science mission based on the selected location?
- How will you prioritize and pack supplies in the cargo bay following design criteria?

Imagine

The year is 2025 and you are part of a four-member team traveling toward the Moon. As your spacecraft enters lunar orbit, you spot the base camp. It is located on a crater rim near the lunar South Pole, in near-constant sunlight. This location is not far from supplies of water ice that can be found in the cold, permanently shadowed part of the crater. As your spacecraft descends toward the lunar surface, you suddenly notice that there is a problem with the thrusters. You land safely, but off course, about 25 kilometers (approximately 15 miles) from the base camp. As you look across the charcoal-gray, dusty surface of the Moon, you realize your survival depends on reaching the base camp, finding a way to protect yourself until someone can reach your team, or meeting a rescue party somewhere between your landing site and the habitat. You know the Moon has basically no atmosphere or magnetosphere to protect you from space radiation. The environment is unlike any found on Earth. The regolith, or lunar soil, is a mixture of materials that includes sharp, glassy particles. The gravity field on the Moon is only one-sixth as strong as Earth's. More than 80 percent of the Moon is made up of heavily cratered highlands. Temperatures vary widely on the Moon. It can be as cold as 193 °C (–315 °F) at night at its poles and as hot as 111 °C (232 °F) during the day at its equator. Survival will depend on your mode of transportation and your ability to navigate. Your basic needs for food, shelter, water, and air must be considered. With the Moon's lower gravity, 25 kilometers (approximately 15 miles) is not too far to walk, but you are limited in what you can carry. You can only take seven items with you. What should you take with you and why?

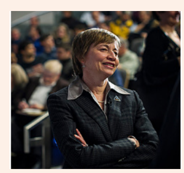
Fun Fact

You are part of the Artemis Generation. Artemis was the Greek Goddess of the Moon and the twin sister of Apollo. Through the Artemis missions, NASA plans to put the first woman and first person of color on the Moon. We have not been back to the Moon since 1972. During the Apollo program of the 1960s and 1970s, NASA sent nine missions to the Moon. Six of them landed astronauts safely on the surface, the only times humans have visited another world.

Learn more:
https://www.nasa.gov/specials/artemis/

Career Corner

Dr. Maria Zuber led NASA's Gravity Recovery and Interior Laboratory (GRAIL) mission to explore the Moon.



Maria Zuber

A geophysicist, Maria is an expert on planetary and space science. She has more than half a dozen NASA missions under her belt and decades of experience unraveling mysteries from Mercury to Mars and beyond. Maria was the first woman to lead a robotic planetary mission for NASA. She also was the first woman to lead a science department at the Massachusetts Institute of Technology (MIT).

Learn more:
https://solarsystem.nasa.gov/people/2200/maria-zuber/

Of the 12 items available, strategize with your team and prioritize the 7 items your team will carry during your journey to the lunar base camp. Your survival depends on your ability to work with other team members to determine not only the value of these items, but how to use them as well.

1. Box of matches
2. Oxygen
3. Food
4. Water
5. Lights with solar-powered rechargeable batteries
6. Magnetic compass
7. Solar powered receiver–transmitter
8. Life raft
9. First aid kit
10. Map of Moon's surface
11. 15 meters (approximately 50 feet) of nylon rope
12. Signal mirror

Plan

- Take out the Lunar Cargo Packing List and have your team decide on a priority list for packing for the Moon. Prioritize the cargo that you will bring to the Moon.
- Draw a 10- by 10-inch square on a large sheet of paper. This space represents the (500-kilogram-unit) cargo bay of your human landing system, which will transport the basic needs and science cargo for the mission. Cut out the six sets of shapes on the Lunar Cargo Polyominoes sheets. Polyominoes are equal-sized squares joined together edge to edge to form a plane geometric figure.
- These shapes represent cargo that you can pack into your human landing system. The number on each shape represents the *percentage of volume* it will occupy in the cargo bay.

Create

- Based on the team's original priority list, fit the shapes in the cargo bay beginning with the supplies you will need the most of. For example, if food is the team's number-one priority, there should be a greater percentage of food packed in the cargo bay.
- Try to pack the cargo so there are no empty spaces. Use only the shapes given. Do not cut to make them fit in the cargo bay.

Test

- Now calculate the percentages of each type of packed cargo. A fully packed cargo bay will equal 100 percent.
- Compare your team's final decision with your original priority list.

Improve

- Repack the cargo bay until the priority list has been followed and space has been used to its maximum capacity.

Share

Think about and answer as a team:

- What are the advantages/disadvantages of your site?
- What resources are available to the astronauts at your landing site?
- Did you obey all the criteria and constraints in this activity?
- Think about how density, mass, and balance can affect human spaceflight. How would your team pack the payload based on density, mass, and balance? Discuss various packing solutions.

- How did your team's final cargo bay packing solution compare to your original priority list?
- Do you have enough evidence that NASA would agree with the priority packing your team has chosen?

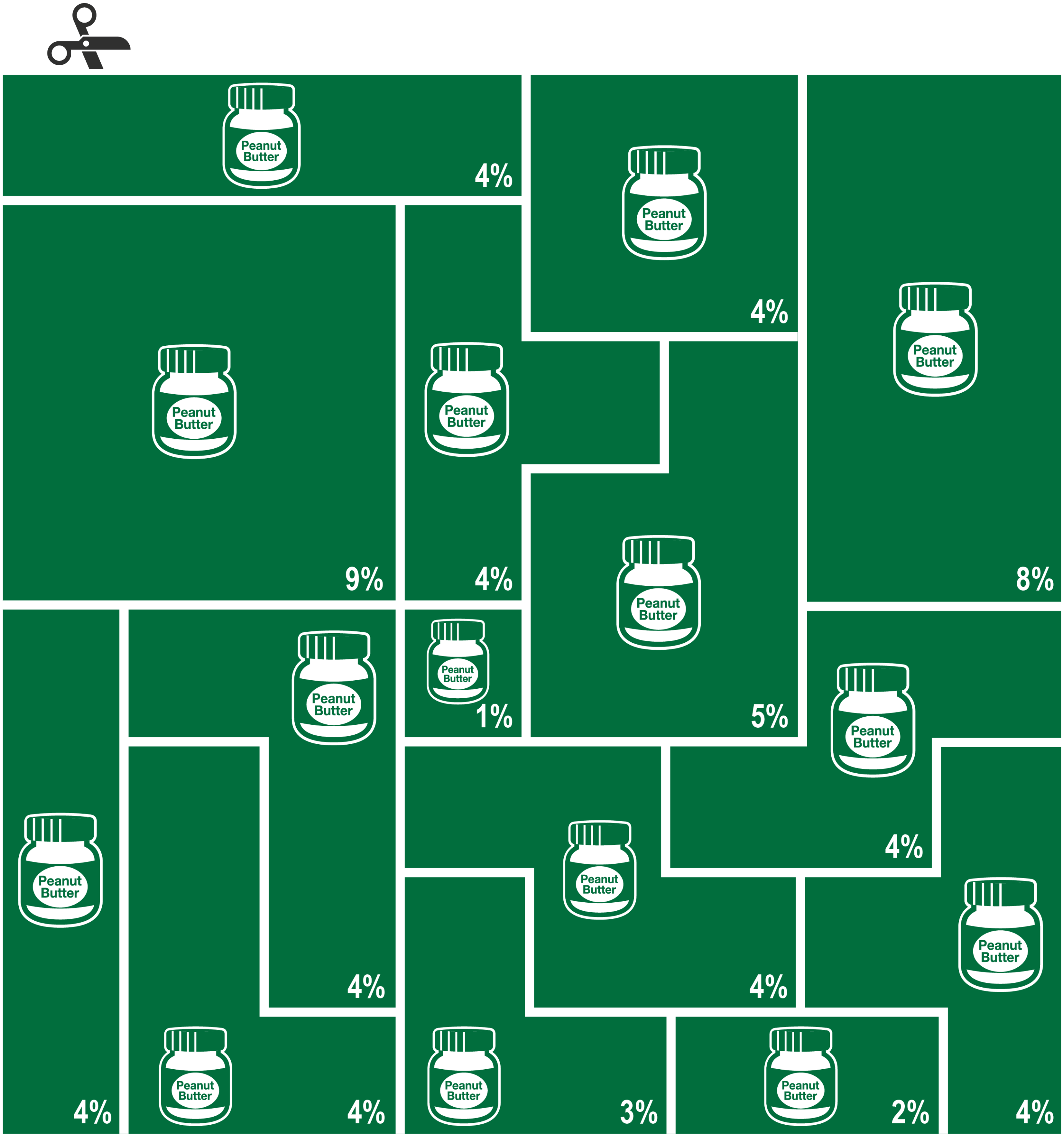
Lunar Cargo Packing List

Priority	Type of Cargo	Percentage of Packed Cargo
	Food Examples: Dried, frozen, canned, and packaged foods, such as tortillas and peanut butter	
	Supplies Examples: Spacesuits, clothing, medical supplies, and toiletries	
	Life Support Examples: Oxygen, water, air filters, water purification system	
	Science Equipment Examples: Shovels, pickaxes, drills, robots, and rotary wire brushes	
	Power Equipment Examples: Generators, wires, electrical cords, outlets, light bulbs, and solar cells	
	Building Equipment Examples: Power tools, construction materials, bricks, and metal structures	

Total Percentage

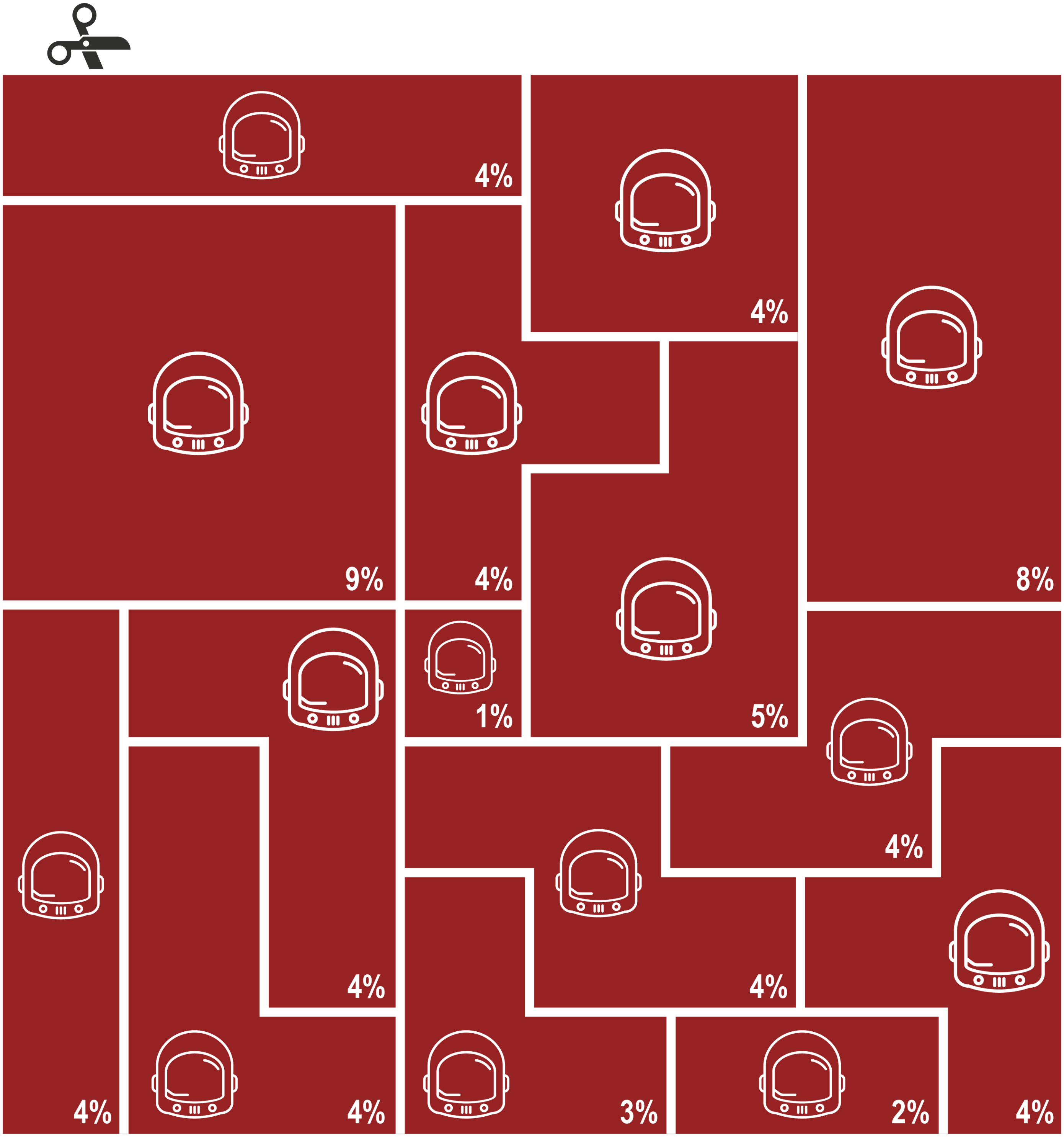
Lunar Cargo: Food Polyominoes

Instructions: Cut out the cargo shapes along the lines. These shapes represent one of the six kinds of cargo that need to be packed for the Moon. (Refer to the Lunar Cargo Packing List worksheet.)



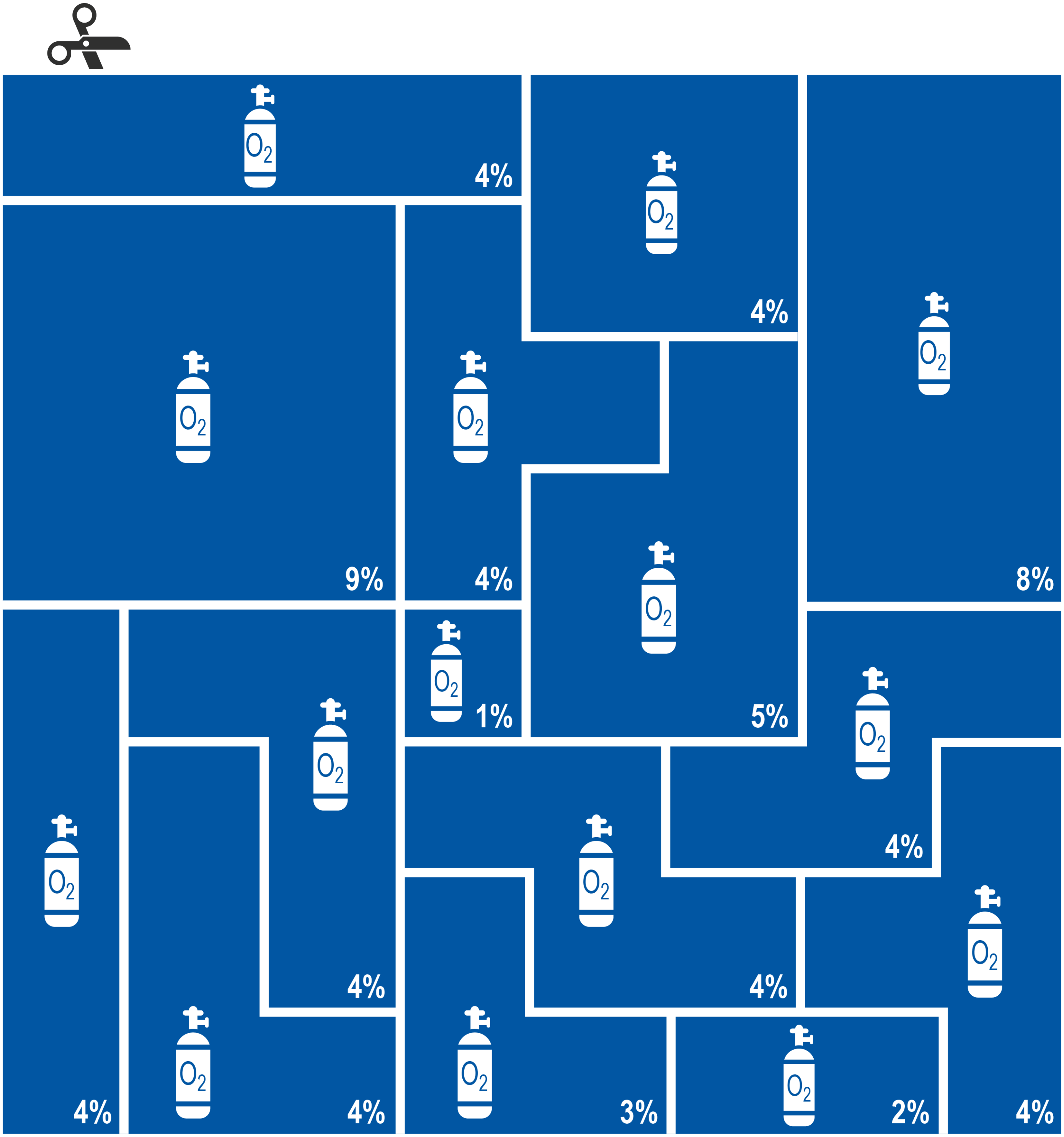
Lunar Cargo: Supplies Polyominoes

Instructions: Cut out the cargo shapes along the lines. These shapes represent one of the six kinds of cargo that need to be packed for the Moon. (Refer to the Lunar Cargo Packing List worksheet.)



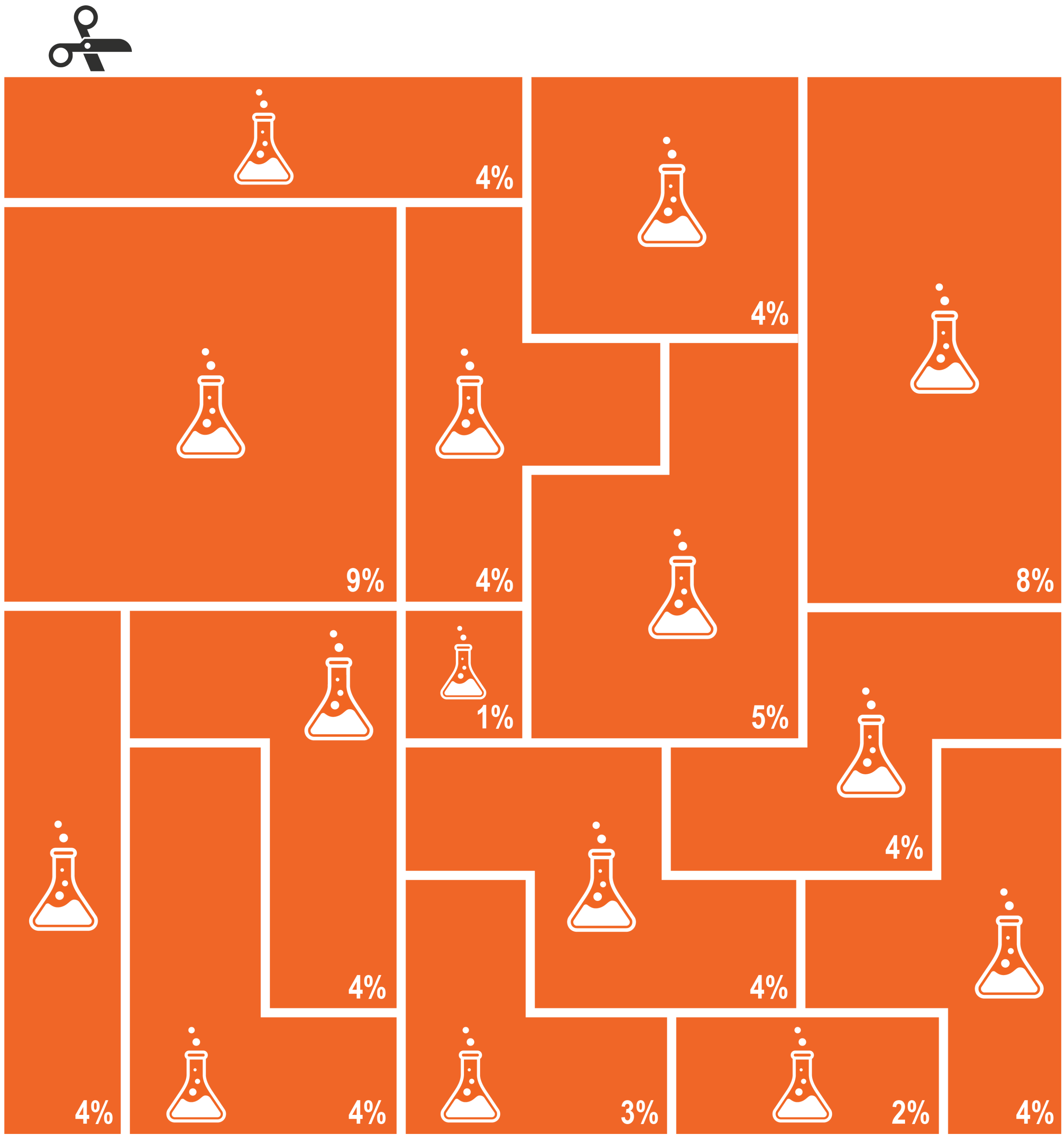
Lunar Cargo: Life Support Polyominoes

Instructions: Cut out the cargo shapes along the lines. These shapes represent one of the six kinds of cargo that need to be packed for the Moon. (Refer to the Lunar Cargo Packing List worksheet.)



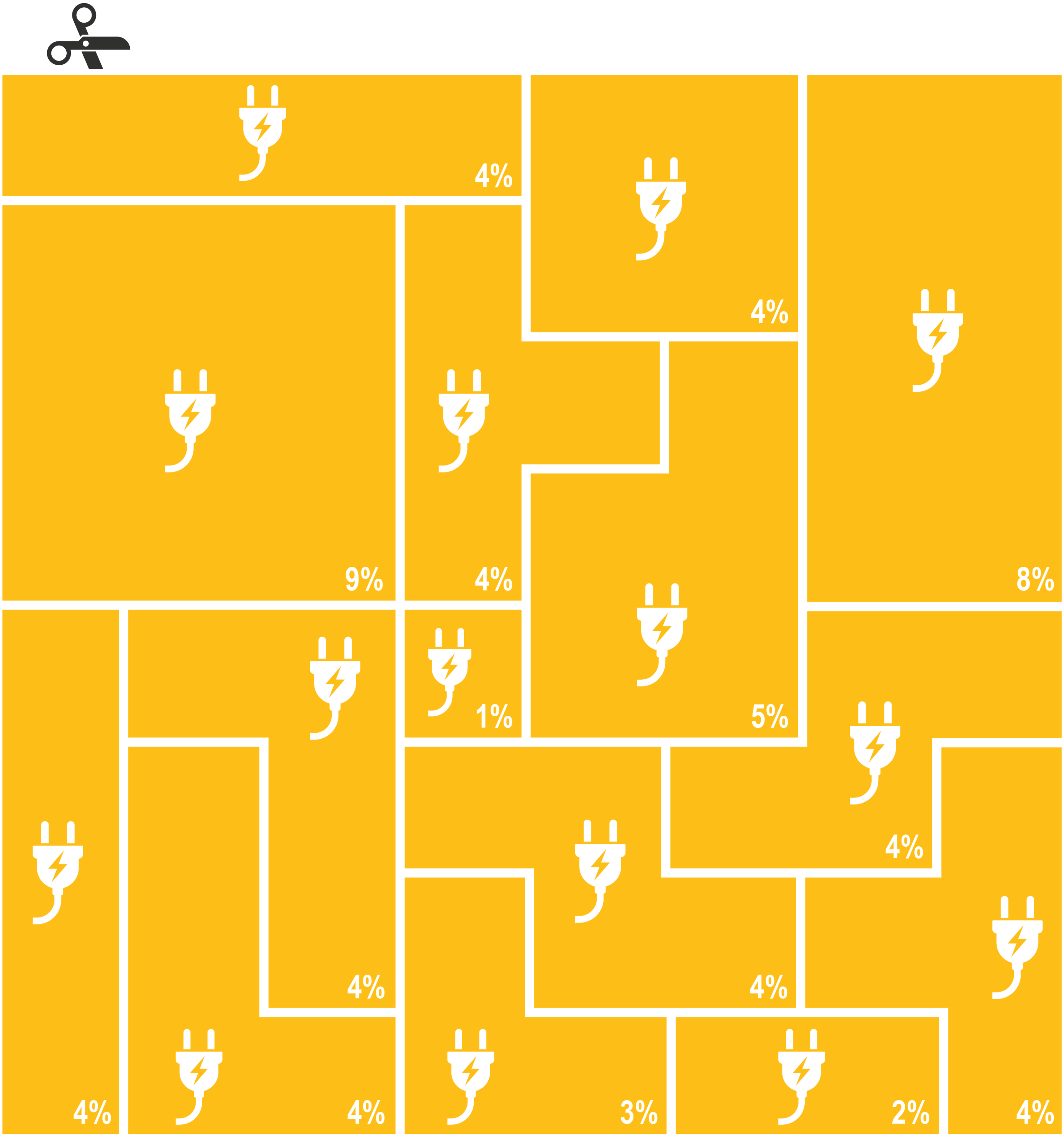
Lunar Cargo: Science Equipment Polyominoes

Instructions: Cut out the cargo shapes along the lines. These shapes represent one of the six kinds of cargo that need to be packed for the Moon. (Refer to the Lunar Cargo Packing List worksheet.)



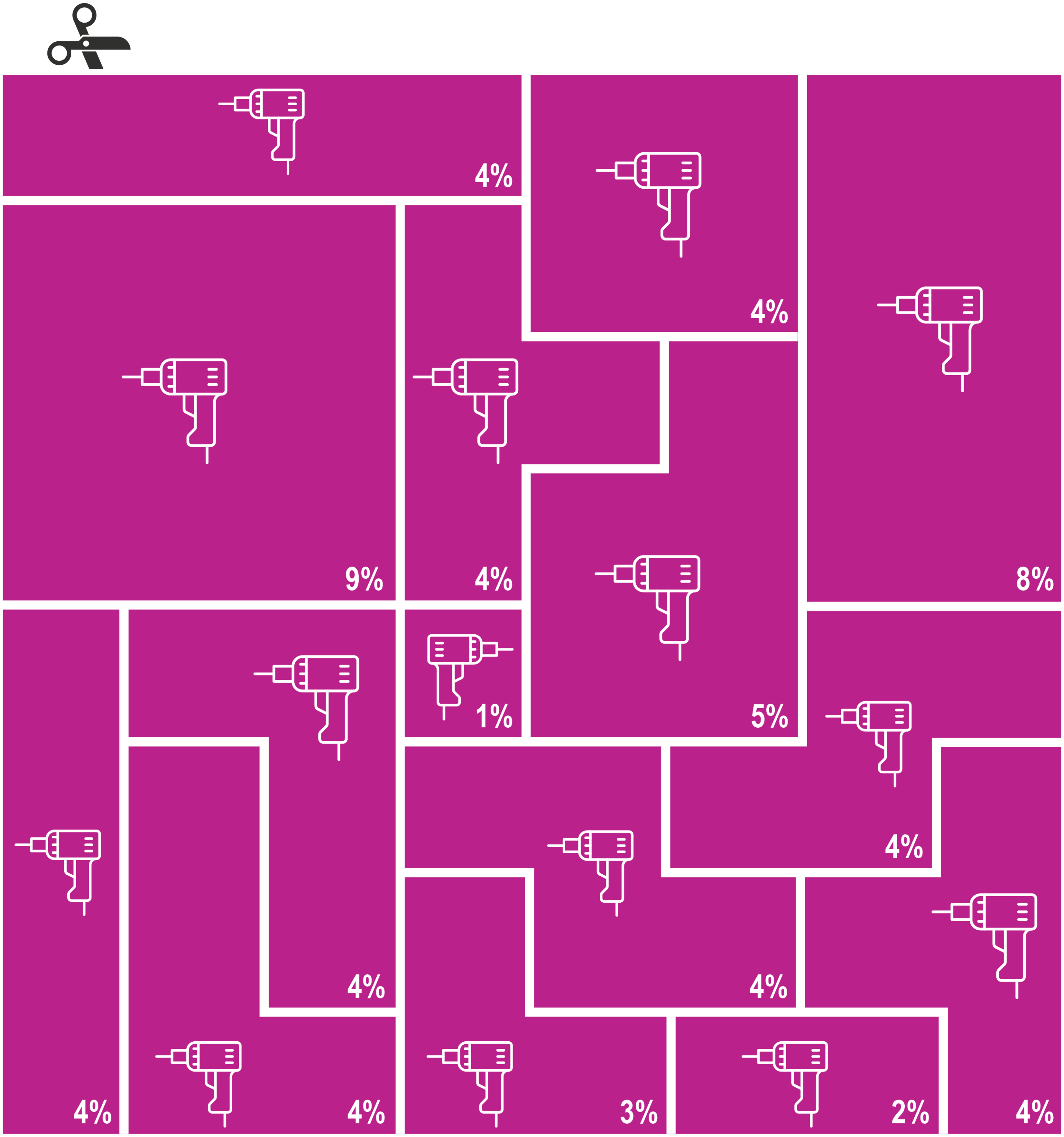
Lunar Cargo: Power Equipment Polyominoes

Instructions: Cut out the cargo shapes along the lines. These shapes represent one of the six kinds of cargo that need to be packed for the Moon. (Refer to the Lunar Cargo Packing List worksheet.)



Lunar Cargo: Building Equipment Polyominoes

Instructions: Cut out the cargo shapes along the lines. These shapes represent one of the six kinds of cargo that need to be packed for the Moon. (Refer to the Lunar Cargo Packing List worksheet.)



Activity Four: Safe Landing on the Lunar Surface

Educator Notes

Learning Objectives

Students will use the engineering design process to

- Identify the challenges of landing a lunar lander on the surface of a body without an atmosphere.
- Design, build, and improve a model of a lunar lander that can slow its descent using the downward thrust of a balloon.
- Graph the speed with respect to elevation of a model lunar lander.

Challenge Overview

In this challenge, students will work in teams to design and build a model of a lunar lander that will use the thrust of balloons to slow its rate of descent. The goal of the challenge is to slow the lander's rate of descent as much as possible to simulate a soft landing on the lunar surface. Students will drop their landers from a height of 2 meters both with and without the use of propulsion, and they will use stopwatches, slow-motion video, and/or video analysis software to measure the effects of propulsion on their landers' rates of descent.

Suggested Pacing

120 to 180 minutes

National STEM Standards

Science and Engineering (NGSS)	
Disciplinary Core Ideas • MS-PS2-2 Motion and Stability: Forces and Interactions: Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. • MS-PS2-4 Motion and Stability: Forces and Interactions: Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects. • 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* • Stability and Change: Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales.	*Crosscutting Concepts (continued)* • Systems and System Models: Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy and matter flows within systems. *Science and Engineering Practices* • Planning and Carrying Out Investigations: Planning and carrying out investigations to answer questions or test solutions to problems in 6–8 builds on K–5 experiences and progresses to include investigations that use multiple variables and provide evidence to support explanations or design solutions. • Engaging in Argument From Evidence: Engaging in argument from evidence in 6–8 builds from K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world. • Analyzing and Interpreting Data: Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.
Technology (ISTE)	
Standards for Students • Innovative Designer 4c: Students develop, test, and refine prototypes as part of a cyclical design process.	*Standards for Students (continued)* • Computational Thinker 5b: Students collect data or identify relevant data sets, use digital tools to analyze them, and represent data in various ways to facilitate problem solving and decision making.
Mathematics (CCSS)	
Mathematical Practices • CCSS.MATH.CONTENT.8.EE.B.5: Graph proportional relationships, interpreting the unit rate as the slope of the graph. Compare two different proportional relationships represented in different ways. For example, compare a distance–time graph to a distance–time equation to determine which of two moving objects has greater speed.	

Activity Preparation

The educator should

- Read the introduction and background information, the Educator Notes, and the Student Handout to become familiar with the challenge.
- Print the Student Handout for each team.
- Select the method students will use to measure the motion of their landers (e.g., stopwatches, slow-motion video, or video analysis software).

- Consider the ability range of students and whether most students will have access to smartphones.
- If using video analysis software, several free or inexpensive sources are available online that can be used for this activity (e.g., Tracker, Logger Pro, and Video Physics).

- Gather and prepare materials for student designs.
- Prepare the drop zone.
  - On a wall, mark a starting point 2 meters from the floor and ensure there is a clear path to the floor.
  - If using a smartphone for slow-motion measurements, place clear reference marks at 20-centimeter intervals from the 2-meter mark, all the way down to the floor.
  - If students have already completed the NASA activity “Sculpting Lunar Geology,” which is also contained in this guide, consider allowing students to use their replica landing sites as a target for the drop test.

Materials

- Tape
- Scissors
- Balloons of various size
- Variety of lightweight materials (e.g., foam cups or plates, soda straws, index cards, etc.)
- Small, heavy items for ballast (e.g., washers, coins, marbles, etc.)
- Clothespins or binder clips
- Meterstick or measuring tape
- Stopwatch or smartphone with slow-motion video camera application
- Video camera and computer if using video analysis software

Safety

- Ensure that students are practicing safe cutting techniques when building their landers.
- Ensure that students do not stand on any unstable surfaces, such tables or chairs, when performing their drop tests.
- Ensure that students’ model landers do not contain sharp or pointed surfaces that could present a hazard during the drop tests.
- Ensure that the drop zone is clear of students and items that may be in the path of falling landers.
- Use a balloon pump or designate a single person to inflate each balloon to minimize the risk of spreading germs.
- Use caution and wear eye protection when inflating, handling, and releasing landers during drop tests. If a balloon pops, loose debris may be propelled and present an eye hazard.

Introduce the Challenge

- Provide context for this activity using the introduction and background information in this guide. Discuss how a spacecraft’s engines can provide downward thrust to counteract the force of gravity not only at launch, but also during a landing to slow its descent. Discuss the difficulties in landing a lander on the surface of a terrestrial body that does not have an atmosphere (no atmospheric braking, no use of parachutes, and no aerodynamic control surfaces).
- Explain the role of engineers in designing technology to solve problems. Share the NASA for Kids video “Intro to Engineering.” https://www.youtube.com/watch?app=desktop&v=wE-z_TJyzil
- Group students into teams of three to five. Consider assigning roles and tasks to individual students within the team. See the Teamwork section at the beginning of the guide for suggestions.
- Distribute the Student Handout and scratch paper.
- Explain the challenge to students:
  - Each team will use the available materials to build a model lunar lander.
  - The lander must incorporate one or more inflated balloons into its design.

- The lander must be sturdy enough that it can be dropped from a height of 2 meters without being damaged.
- Each team will record the time the lander took to fall from a height of 2 meters both with and without the use of a balloon to provide thrust.
- The goal is to use the thrust of the balloon to slow the rate of descent as much as possible.

- Explain procedures for retrieving materials.

Criteria	Constraints
Lander must use at least one inflated balloon.	May only use everyday, readily available supplies.
Design must incorporate landing legs that result in a stable, upright landing position after drop tests.	May not use parachutes or other items designed to create drag.
Lander must survive drop tests from a height of 2 meters.	

Facilitate the Challenge

Ask

Engage students with the following discussion questions:

- Why doesn't NASA use parachutes for its lunar lander?
  - Possible answer: Parachutes slow an object's descent using drag in the atmosphere. Because the Moon has very little atmosphere, a parachute would not work on a lunar lander.
- What factors could make your lander unstable as it descends?
  - Possible answers:
    - Lander is top-heavy or unbalanced and wants to flip.
    - Thrust from balloon is not directed straight downward.
- What other problems do you anticipate encountering during the challenge?
  - Possible answers:
    - Building the lander strong enough to survive the fall intact.
    - Being accurate enough with the stopwatch to collect good data.
- Does your team have any other questions about the challenge before you begin?

Imagine

- Before allowing students to see the supplies, have them imagine how they would design a lander that could safely land on the lunar surface.
- Ask students to individually sketch an initial design.
- Allow students time to observe the available materials and work in their teams to brainstorm how the materials could be used to create a model lander.

Plan

- Have teams sketch a second design for their lander that incorporates the materials available to them.
- Ensure that teams label each major part along with its purpose and what materials it will be made from.
- Each design must incorporate at least one design idea from each team member.

Share With Students

Brain Booster

NASA has selected three companies (Blue Origin-led team, Dynetics, and SpaceX) to develop human landers for the Artemis missions to the Moon. Each is developing its own unique designs. Be sure to follow their progress.

Learn more: https://www.nasa.gov/content/humans-on-the-moon-0

On Location

Named for NASA astronaut Neil Armstrong and located within Edwards Air Force Base in western California's Mojave Desert, Armstrong Flight Research Center (AFRC) serves as a prime location for NASA's flight research and test projects. This includes the Lunar Landing Research Vehicle (LLRV) that was used to train Apollo astronauts in piloting their lunar landers to the surface of the Moon.

For more information on Armstrong Flight Research Center and the LLRV, visit https://www.nasa.gov/centers/armstrong/Features/armstrong_recalls_first_moon_landing.html

Create

- Have teams construct their landers.
- Ensure that an inflated balloon is incorporated into the build, as it may be difficult to attach once the lander is complete. The balloon's nozzle should NOT be tied. It should be rolled and held shut with a binder clip or clothespin.
- The teams' landers should be sturdy enough to be dropped from a height of 2 meters without damage.

Tip: If students' landers are unstable, encourage them to place most of the weight of their lander below the balloon. Also have them add mass where needed to balance it out. The thrust of the balloon can be directed more downward by securing the balloon to the lander near the nozzle.

Test

To conduct the drop test, one student will operate the data collection device (stopwatch or slow-motion camera) while another releases the model lander in the drop zone from a height of 2 meters. For the first test, the binder clip or clothespin will remain in place, keeping the balloon's nozzle closed. For the second test, before releasing the lander, the binder clip or clothespin must be removed from the nozzle of the balloon. To ensure a smooth drop test, the nozzle of the balloon should be pinched closed while the binder clip or clothespin is removed, and then released at the same time the lander is released for the test.

Have students follow the drop test procedure for the testing method you have chosen (stopwatches, slow-motion video, or video analysis software).

1. If using a stopwatch:
   - With the balloon still sealed, have students record the time it takes for their lander to fall from a height of 2 meters.
   - Have students repeat the drop test with the nozzle of the balloon opened, again having students record the time of descent.
   - Have students calculate and record the average speed for each drop.
   - Using their data from both trials, have each team create a bar graph that shows the average speed of their lander both with and without the use of thrust from the balloon to slow its descent.
2. If using a slow-motion camera, such as a smartphone application:
   - With the balloon still sealed, have students record the time it takes for their lander to fall from a height of 2 meters in 20-centimeter increments. This can be accomplished by measuring the time elapsed as the lander passes each of the 20-centimeter reference marks on the wall.
   - Have students repeat the drop test with the nozzle of the balloon opened, again having students record the time it takes for the lander to fall in 20-centimeter increments.
   - Have students calculate and record the average speed of their lander at each of the 20-centimeter intervals.
   - Using their data from both trials, have each team create a line graph that shows their lander's speed at 20-centimeter intervals as it makes its descent both with and without the use of thrust from the balloon to slow its descent.
3. If using video analysis software:
   - Have students record two videos of their drop test, one with the balloon still sealed and another with the nozzle opened.
   - Have students upload their videos into the software for analysis.
   - Have students use the software to measure the acceleration of their lander both with the nozzle sealed and with the nozzle opened.
   - Using the modeling capabilities of the video analysis software, have students graph the acceleration of their lander in both of their trial videos.

If students are not familiar with calculating the speed of objects, share the following information:

To find the speed of the lander at any distance interval, or to find its average speed during its entire descent, use the speed formula: $s = d/t$. The speed (s) of the lander is equal to the distance (d) it has traveled (distance fallen), divided by the time (t) it took to travel that distance. Using metric units, measure the distance in meters (m) and the time in seconds (s). This will result in the speed being in meters per second (m/s).

Improve

- Have each team identify at least two areas in which their lander design can be improved. Remind students that the force of gravity pulling on their lander is dependent on the mass of their lander. This force is called weight. If their landers have less mass, they will also have less weight and will be pulled down with less force. The thrust from their balloons is the force that opposes the weight of the landers and causes the net downward force on the landers to decrease. Increasing the thrust will also cause the landers to fall more slowly. Balancing the thrust and weight will cause the landers to hover, and having too much thrust will overcome the weight of the landers and cause them to increase in altitude.
- Allow each team additional time and materials to incorporate these changes into their landers.
- Have students repeat their drop tests and determine if their design changes improved the performance of their landers.

Share

Engage students with the following discussion questions:

- What were some difficulties your team faced during the initial design and build process, and how did you overcome them?
- Were you surprised by the performance of your lander? Explain.
- How were you able to improve your lander during the redesign phase? What design changes did you make, and how did they improve your lander's performance?
- On a scale of 1 to 10, rate how your lander performed. Rate the landers of other teams as well. Were there any designs or features from other teams' landers that impressed you?
- If you could create a lander with additional materials you did not have available today, what materials would you use, and how would they improve the performance of the lander?

Students could also present their findings by creating a poster presentation, a computer graphical presentation, an oral report, or a written log or journal of their team's experimentation and results.

Optional: Share student results on social media using #NextGenSTEM. Be sure to include the module and activity name.

Extensions

- Have students make a two-stage lunar lander. A smaller upper stage with its own sealed balloon can be added to their current lander. After the lander has touched down on the surface, the upper stage can be disconnected from the lower stage and its balloon released. The upper stage will launch upward off the lunar surface. This is similar to how the Apollo Lunar Lander used both a descent stage and an ascent stage for landing on the Moon and returning to lunar orbit.
- Have students create a NASA Docking Adapter from the "Model a Spacecraft Docking System" activity in the Crew Transportation With Orion guide (https://www.nasa.gov/sites/default/files/atoms/files/np-2020-02-2805-hq.pdf) and attach it to their landers. They can then create models of the Orion crew module that can rendezvous and dock with their landers in lunar orbit.

Additional Resources

- This activity is written as an engineering design challenge in which students build and construct objects using common, everyday items. In the Materials ISS Experiment–X (MISSE–X) activity, students can explore how NASA tests different materials for their suitability for use in the construction of NASA hardware: https://www.nasa.gov/stem-ed-resources/best-technology-demonstration.html
- These NASA blog posts describe liquid rocket engines and provide video links: https://blogs.nasa.gov/J2X/tag/marshall-space-flight-center/
- The Tensegrity Planetary Lander, also called the Super Ball Bot, is a project that utilizes a radically different approach to landing and maneuvering a robotic craft on a planetary surface: https://www.nasa.gov/content/super-ball-bot

Activity Four: Safe Landing on the Lunar Surface

Student Handout

Your Challenge

You will work in teams to design and build a model of a lunar lander that will use the thrust of balloons to slow its rate of descent as much as possible to simulate a soft landing on the lunar surface. You will then drop your landers from a height of 2 meters in a series of trials, both with and without the use of propulsion, and collect and graph data of your lander's descent. Finally, you will make design changes and implement them into your lander to improve its performance.

Criteria	Constraints
Lander must use at least one inflated balloon.	May only use everyday, readily available supplies.
Design must incorporate landing legs that result in a stable, upright landing position after drop tests.	May not use parachutes or other items designed to create drag.
Lander must survive drop tests from a height of 2 meters.	

Ask

Discuss the following questions with your team and be prepared to share your answers aloud:

- Why doesn't NASA use parachutes for its lunar lander?
- What factors could make your lander unstable as it descends?
- What problems do you anticipate encountering?
- Does your team have any other questions about the challenge before you begin?

Imagine

- How would you design a craft that could safely land on the lunar surface?
- Sketch your own design of a lunar lander.
- Observe the building materials that are available for your team to use. Brainstorm with your team how they can be used in your model lander.

Plan

- As a team, sketch a design for your lander that incorporates the supplies available to you.
- Label each major part along with its purpose and what materials it will be made from.
- Your sketch must include at least one design idea from each team member.

Create

- Begin constructing your lander following the plans in your sketch. Be sure to use an inflated balloon in your design during the construction process, as it may be difficult to attach once your lander is completed. The balloon's nozzles should NOT be tied. They should be sealed by rolling the nozzle and pinching it shut with a binder clip or clothespin. This will ensure that the balloon is easy to release.

Fun Fact

How do you reliably start a rocket engine in space? Hypergolic fuels ignite spontaneously when mixed without the need of a spark or heat. They are, however, highly toxic. Researchers are developing nontoxic "green" propellants that are less harmful to the environment, increase fuel efficiency, and are less hazardous to work with.

Learn more: https://www.nasa.gov/content/gpim-spacecraft-to-validate-use-of-green-propellant

Career Corner

Enjoy designing and building spacecraft? Have a passion for solving problems and innovation? NASA employs over 20 types of engineers. Come explore the diverse career paths available and prepare to become part of the NASA team.

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

- After completing your lander, practice dropping it, with the balloon still sealed, from a height of 2 meters. Your lander must be sturdy enough to survive multiple 2-meter drops without damage.
- Now practice releasing the nozzle of your balloon as you drop your lander. The thrust of the balloon should be directed downward, and the lander should descend without traveling sideways. If you are having trouble keeping your lander stable, ask the instructor for advice, and then work on your design.

Test

- Your team will be making two official drops with your lander, first with the balloon's nozzle sealed, and then with the nozzle released.
- To conduct the drop test, one student will operate the data collection device (stopwatch or slow-motion camera) while another releases the model lander in the drop zone from a height of 2 meters. For the first test, the binder clip or clothespin will remain in place, keeping the balloon's nozzle closed. For the second test, before releasing the lander, the binder clip or clothespin must be removed from the nozzle of the balloon. To ensure a smooth drop test, the nozzle of the balloon should be pinched closed while the binder clip or clothespin is removed and then released at the same time the lander is released for the test.
- Carefully follow instructions on how to collect data for your tests and how to calculate the speed of your lander during its descent.
- Graph your results as directed and determine if the thrust from the balloon slowed the descent of your lander.

Improve

- As a team, identify at least two ways in which you can improve upon the design of your lander. Sketch them out, detailing what changes you will make to your design.
- Gather the necessary materials and incorporate your changes into your lander model.
- Repeat the drop tests, collecting data as you did before.
- Graph your new results and compare them to those of the previous drop tests to determine if the changes in your design improved the performance of your lander.

Share

- What were some difficulties your team faced during the initial design and build process, and how did you overcome them?
- Were you surprised by the performance of your lander? Explain.
- How were you able to improve your lander during the redesign phase? What design changes did you make, and how did they improve your lander's performance?
- On a scale of 1 to 10, rate how your lander performed, and then rate the other teams' landers. Were there any designs or features from other teams' landers that impressed you?
- If you could create a lander with additional materials that you did not have available today, what materials would you use, and how would they improve the performance of the lander?

Appendix A.—Rubric for Engineering Design Process (EDP)

EDP Step	Novice (0)	Apprentice (1)	Journeyperson (2)	Expert (3)	Score
Identify the problem (Ask)	Student does not identify the problem	Student incorrectly identifies the problem	Student identifies part of the problem	Student fully and correctly identifies the problem	
Brainstorm a solution (Imagine)	Student does not brainstorm	Student generates one possible solution	Student provides two solutions	Student provides three or more possible solutions	
Develop a solution (Plan)	Student does not select or present a solution, or the solution is off-task	Student presents a solution that is incomplete or lacking details	Student selects a solution but does not consider all criteria and constraints	Student selects a solution that considers all criteria and constraints	
Create a prototype (Create)	Student does not directly contribute to the creation of a prototype	Student creates a prototype that does not meet problem criteria and constraints	Student's prototype meets most problem criteria and constraints	Student creates a prototype that meets all problem criteria and constraints	
Test a prototype (Test)	Student does not contribute to the testing of the prototype	Student conducts tests that are irrelevant to the problem or do not accurately assess strengths and weaknesses of the prototype	Student conducts carefully performed tests that consider one to two strengths and weaknesses of prototype	Student conducts relevant and carefully performed tests that consider three or more strengths and weaknesses of prototype	
Redesign based on data and testing (Improve)	Student does not contribute to the redesign	Student does not improve the design or address concerns	Student addresses one concern to improve the design	Student addresses two or more test-based concerns to improve the design	
Communicate results from testing (Share)	Student does not communicate results	Student shares random results	Student shares organized results but results are incomplete	Student shares detailed, organized results with group	
				Total	

Appendix B.—Rubric for Scientific Research Process (SRP)

SRP Step	Novice (0)	Apprentice (1)	Journeyperson (2)	Expert (3)	Score
Pose questions	Student does not identify the question	Student incorrectly identifies the question	Student identifies part of the question	Student identifies the question completely	
Develop hypothesis	Student does not state hypothesis	Student generates a hypothesis that is not clearly stated or well thought out and is not testable	Student generates a hypothesis that is clearly stated and testable	Student generates a hypothesis that is formulated using appropriate terms and is testable	
Plan the investigation	Student does not plan investigation	Student does plan the investigation, but it is largely incomplete (no testing of hypothesis)	Student does plan the investigation but does not adequately test the hypothesis previously stated	Student does plan the investigation and adequately tests the hypothesis previously stated	
Assemble data	Student does not present data	Student does present data but uses inappropriate presentation for the type of data	Student does present data and uses the appropriate presentation for the type of data	Student presents data that show trends or patterns (insight) and uses the appropriate presentation for the type of data	
Document conclusions	Student does not document conclusions	Student does document conclusions, but the conclusions are incomplete or suggests student does not understand the conclusion	Student does document conclusions and shows an understanding of evidence interpretation	Student does document conclusion and shows understanding of evidence interpretations as well as any limitations	
Present findings	Student does not communicate results	Student shares random results	Student shares organized results, but results are incomplete	Student shares detailed, organized results with group	
				Total	

Appendix C.—Glossary of Key Terms

Cargo. Goods carried on a large vehicle

Central crater uplift. A mountain in the center of large (greater than 40 kilometers in diameter) impact craters

Cinder cone. A low, broad, dark, cone-shaped hill formed by an explosive volcanic eruption

Constraint. Limitation or restriction

Crater ejecta. Material thrown out from and deposited around an impact crater

Criteria. Standard for evaluating

Dome. A low, circular, rounded hill suspected to be a volcanic landform

Highlands. Bright areas of the Moon composed of countless overlapping craters (ranging from 1 to over 1,000 meters) that formed when meteorites crashed into the Moon

Illumination. Period during which a lunar South Pole region site receives direct sunlight

Impact crater. A roughly circular hole created when something, such as a meteorite, struck the Moon's surface

Kelvin. The kelvin (K) is the standard international (SI) unit of thermodynamic temperature

Lava flow. A breakout of magma from underground onto the surface

Maria. Areas that formed when lava flows filled in low places. The low places are mostly inside huge basins that were formed by large meteor impacts. The maria cover 16 percent of the Moon's surface.

Multi-ringed basin. Huge impact crater surrounded by circular mountain chains

Optimize. Optimize is making the best or most effective use of a resource

Orbiting lunar habitat. An outpost orbiting the Moon that provides vital support for long-term human return to the lunar surface as well as a staging point for deep space exploration

Polyominoes. Equal-sized squares joined together edge to edge to form a plane geometric figure

Priority. The fact or condition of one thing being regarded as more important than another

Ray. Bright streak of material blasted out from an impact crater

Rille. A channel in the lunar maria formed by an open lava channel or a collapsed lava tube

Slope. The measure of the rise (steepness) or fall (inclination) of a feature relative to the horizontal plane

Terraced crater walls. Steep walls of an impact crater with "stair steps" created by slumping due to gravity and landslides

Topographic map. A detailed, two-dimensional representation of a three-dimensional surface that gives an accurate representation of its features and shape

Volatile. A chemical element or compound that is a gas at room temperature and has been deposited in the top layers of the Moon's surface

Water ice. Frozen water mixed in the regolith (lunar soil) on the Moon in the form of grains

Wrinkle ridge. A long, narrow, wrinkly, hilly section in the maria

National Aeronautics and Space Administration
NASA Headquarters
E Street Southwest
Washington DC 20024-3210

www.nasa.gov

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