



# Lunar Surface Exploration Guide

Grades 5-8



ENGINEERING DESIGN AND TECHNOLOGY

## Next Gen STEM-Moon

For more about Next Gen STEM visit [www.nasa.gov/stem/nextgenstem/index.html](http://www.nasa.gov/stem/nextgenstem/index.html)

A decorative footer with a blue and orange gradient background. It features various technical diagrams, including a satellite, a rocket, and a space station. Mathematical formulas are scattered throughout, such as  $a^2 - b^2 = (a-b)(a+b)$ ,  $a^3 - b^3 = (a-b)(a^2 + ab + b^2)$ , and  $h\nu = A + \frac{mv^2}{2}$ .

Education Product	
Educators and Students	Grades 5-8

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# Preface

*Lunar Surface Exploration* 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 are suited for both formal and informal education settings as well as for families at home. Each activity is aligned to national standards for science, technology, engineering, and mathematics (STEM), and the NASA messaging is current as of June 2023.







# 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 \(NGSS\)](#) middle school 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](#) middle school 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	Global Collaborator	Ask Questions and Define Problems	Develop and Use Models	Plan and Carry Out Investigations	Construct Explanations and Design Solutions	Ratios and Proportional Relationships	The Number System	Statistics and Probability	Geometry
Activity 1 Electrostatic Moon Duster	✓		✓	✓	✓	✓		✓	✓		✓	✓	✓	✓		
Activity 2 Drilling on the Moon	✓			✓		✓		✓	✓	✓		✓				
Activity 3 Print a Lunar Habitat	✓			✓			✓	✓		✓			✓	✓		✓
Activity 4 Sample Return Mission	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓

# CULTURALLY RESPONSIVE EDUCATION (CRE)

There are six culturally responsive strategies for student engagement. The table below shows the cultural capital approach and corresponding icon, and indicates how strategies are integrated throughout the guide. Each example corresponds to at least one of six major strategies as noted below and recommended for best practices in CRE.

Section Title (page #)	CRE Strategy	CRE Tips
Activity One, Two, Three, and Four: Introduce the Challenge (pg.9, 16, 24, 32)	 Making Cultural Connections	<ul style="list-style-type: none"> <li>The students are introduced to the challenge using a video</li> <li>Allow opportunity to activate prior knowledge and offer complementary sources such as a video</li> </ul>
Teamwork section (pg.3)	 Power and Participation	<ul style="list-style-type: none"> <li>Consider assigning teams team roles. An example is found in the Teamwork section of the guide</li> </ul>
Glossary of key terms (pg.44) Activity One - ask section (pg.11) Share Section of each activity (pg.13,21,28,36)	 Language and Communications	<ul style="list-style-type: none"> <li>Give students a copy of the glossary or make it accessible to all students</li> <li>Have students share information or examples in groups</li> <li>Have students present their final designs to other groups in the class</li> </ul>
Engineering Design Process Rubric pg. 43 Ask section for each activity (pg.11,19,26,35)	 High Expectations	<ul style="list-style-type: none"> <li>There is a rubric provided that may be used for grading</li> <li>Student inquiry and critical thinking can be promoted by asking students to make predictions, which can then be tested</li> <li>Cooperative learning that promotes problem solving</li> </ul>
Plan and Create sections for each activity (pg.12,20,26,36)	 Student Identity and Funds of Knowledge	<ul style="list-style-type: none"> <li>Students design their own prototype to solve a specific challenge. Throughout the planning and creating sections, students are given questions that allow them to self-reflect about their design.</li> </ul>
Share sections for each activity (pg.13,21,28,36)	 Critical Knowledge and Social Justice	<ul style="list-style-type: none"> <li>Make connection to personal/community/cultural knowledge and role models from the community</li> <li>In this activity, the Brain Booster gives students more information about engineers and what they do. Students can find engineers in their community to ask questions.</li> </ul>

Sangam, D., Collins, K.H., & Huling, L. (2023). Identifying and Utilizing Cultural Capital Approach to Implement Culturally Responsive Strategies. STEM Research White Paper Series, Vol.6 No.1, LBJ Institute for STEM Education and Research, Texas State University. <https://lbj-stem.education.txst.edu/Research-and-Publications.html>



# 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 astronauts Tom Marshburn and Matthias Maurer aboard the International Space Station at [www.nasa.gov/stem-content/stemonstrations-engineering-design-process/](http://www.nasa.gov/stem-content/stemonstrations-engineering-design-process/).

**? ASK:** Identify the problem, the requirements that must be met, and the constraints that must be considered.

**💡 IMAGINE:** Brainstorm solutions and research what others have done in the past.

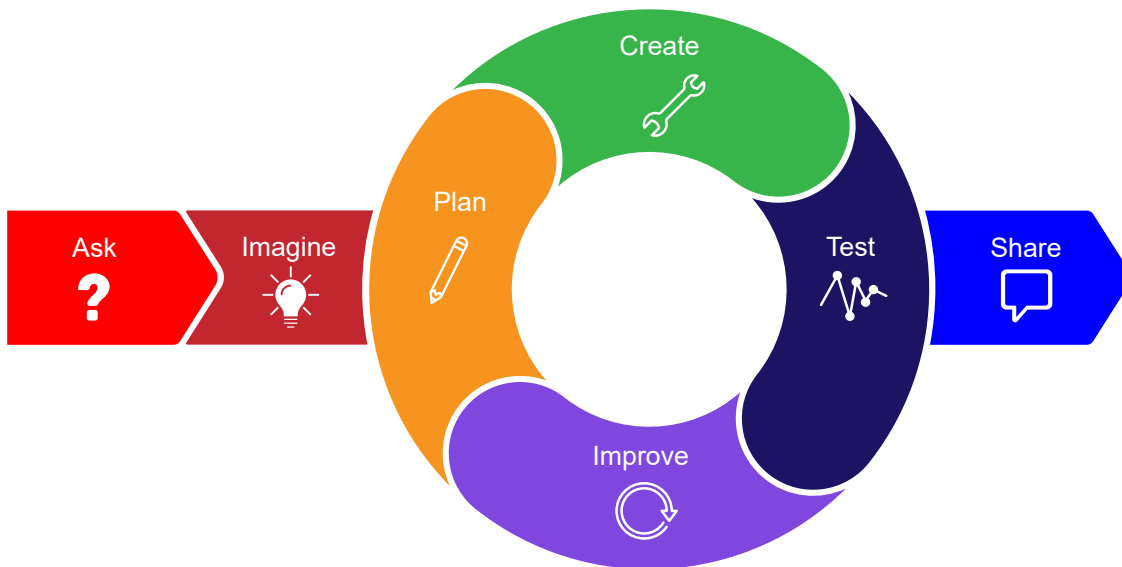
**✏️ PLAN:** Select and sketch a design.

**🔧 CREATE:** Build a model or a prototype.

**📈 TEST:** Evaluate solutions by testing and collecting data.

**🔄 IMPROVE:** Refine the design.

**💬 SHARE:** Communicate and discuss the process and solutions as a group.



## 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 on 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 take on the role of scientists and engineers that will lead the way in lunar surface exploration. Artemis III will land the first woman and the first person of color on the lunar surface in an area that humans have not yet traversed: the lunar South Pole. This is the ideal location for a future base camp given its potential access to ice and other mineral resources. The unexplored south polar regions provide unique opportunities to unlock secrets about the history and evolution of the Earth and Moon, as well as our solar system. NASA's Lunar Surface Innovation Initiative is a technology development portfolio to ensure human and robotic exploration on the Moon. Each activity in this module will allow students to discover problems encountered as well as solutions as we explore the lunar surface. Each activity encourages collaboration to apply the engineering design process to lunar surface exploration and provides a variety of additional resources to help the educator and student experience what it's like to be a NASA scientist and engineer in lunar surface operations.

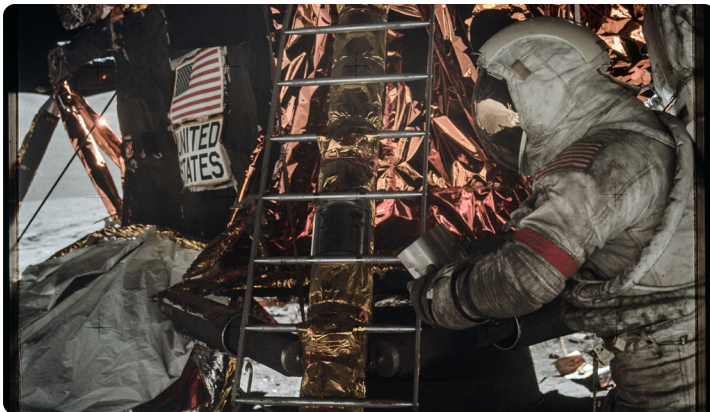
## NASA SPINOFF

The spinoff highlights below are NASA technologies that benefit life on Earth in the form of commercial products. There have been more than 2,000 spinoffs highlighted since 1976; therefore, there is more space in your life than you could ever imagine!

### Measuring Moon Dust to Fight Air Pollution

Moon dust isn't like the stuff that collects on a bookshelf or on tables – it's ubiquitous and abrasive, and it clings to everything. It's so bad that it even broke the vacuum NASA designed to clean the Moon dust off Apollo spacesuits. With NASA's return to the Moon and its orbit, we will need to manage the dust, which is dangerous for people too. The first step is knowing how much dust is around at any given time. Efforts to assess that are already paying off on Earth in the fight against air pollution.

Working as a contributor on a NASA NextSTEP lunar habitat project, a NASA Spinoff company developed an air-quality sensor system to detect and measure the amount of lunar dust in the air. The same technology now also detects pollutants on Earth.



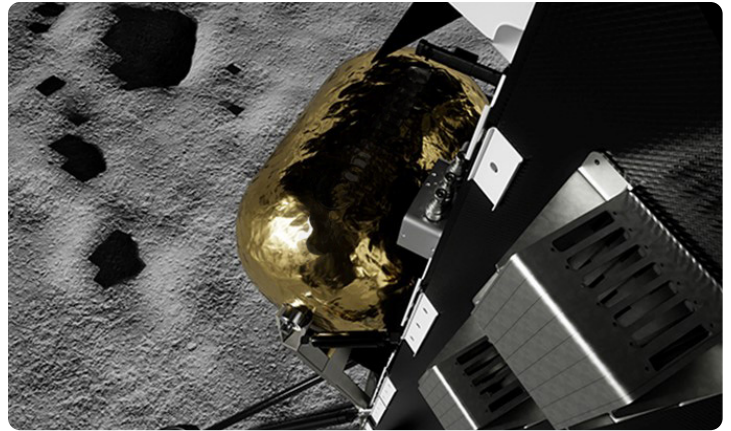
Above: While astronaut Gene Cernan was on the lunar surface during the Apollo 17 mission, his spacesuit collected loads of lunar dust. Credits: NASA. Right: The Space Canary sensor developed by a NASA Spinoff company can detect the ultra-fine lunar dust particles inside a habitat, alerting astronauts should an elevated level of contamination occur. Adapted for use on Earth, the same technology, now renamed the Canary S, can monitor forest fire emissions, evaluate urban air quality, and more. Credit: Lunar Outpost



## With NASA's Help, the Moon Becomes a Commercial Destination

The first of many commercial landers are headed to the Moon, paving the way for future missions. On a Houston-based company's first trip to the Moon under NASA's Commercial Lunar Payload Services (CLPS) initiative, its Nova-C lunar lander will carry both experimental NASA technologies and several other payloads from commercial customers. The International Lunar Observatory Association, for example, bought a ticket for a pair of cameras that will precede the organization's flagship project – a space observatory on the Moon. Other commercial cargo includes a camera system designed by university students, a time capsule containing data from a million customers, and a NASA Spinoff company newest reflective insulation for testing in the harsh lunar environment. But NASA will be this mission's biggest customer, sending science and technology payloads to pave the way for future lunar activities, such as demonstrations of new landing navigation technology, cameras to see how lunar dust interacts with engine plumes, and a device to determine how much interference radio

antennas will experience on the Moon. This is the first of three landers that will be sent to the Moon under NASA's CLPS initiative. More than a dozen other companies have also been selected as part of the CLPS vendor pool, and all have the chance to compete for lunar delivery services via task orders.



One of the commercial partners will test the ability of its new Omni-Heat Infinity thermal-reflective technology to protect parts of the first Nova-C lander to touch down on the Moon. Credit: Intuitive Machines LLC

## INTRODUCTION AND BACKGROUND

NASA must overcome several challenges to explore and inhabit the surface of the Moon. These challenges include dealing with Moon dust, finding resources, building infrastructure, and finding, handling, and transporting fuels.

NASA's exploration of the Moon has always been made possible by working with American companies, and the return to the lunar surface through the Artemis program will continue this collaboration. Through the Commercial Lunar Payload Services (CLPS) initiative, NASA is working with companies to deliver scientific, exploration, and technology payloads to the Moon's surface and orbit. The CLPS model aims to enable new avenues of completing high-value/high-priority scientific investigations and exploration while expanding the lunar economy and build a marketplace on the Moon, where NASA will be one of many customers, along with universities and international partners, sending payloads to the Moon. NASA's goals for CLPS are to enable science at and about the Moon using low- to mid-size commercial landers; enabling NASA to advance technologies and systems on the lunar surface; and to develop a commercial community of service providers for Artemis.

In 2018, nine U.S. companies were selected to be part of a pool of vendors eligible to bid on contracts. A year later, five more vendors were added, bringing the total of CLPS participants to 14. The first payloads heading to the Moon through CLPS are being launched ahead of crewed missions to help NASA better understand how to operate in the lunar environment before landing the next generation of explorers. There are now numerous commercial partners who all offer unique contributions to Commercial Lunar Payload Services. Visit the CLPS website at [www.nasa.gov/commercial-lunar-payload-services](http://www.nasa.gov/commercial-lunar-payload-services) to see all the other technologies being developed that are just waiting for applications here on Earth.

## The Problem with Moon Dust

During the Apollo missions, astronauts faced a high risk of dust-related damage to space hardware and astronaut health. The lunar surface is covered by a layer of dust particles called regolith. The lunar regolith, or **lunar dust** as it is commonly called, was created over billions of years by the bombardment of the solid lunar crust by meteoroids, solar UV flux, solar wind, and radiation. During impacts from micrometeorites, some of the surface particles formed into something called agglutinates, which are fused particles

of impact glass, rock, and mineral fragments. These dust particles can be stirred up during robotic and human exploration activities or released by natural processes such as meteorite impacts. Apollo astronauts noted that lunar dust particles readily stuck to surfaces such as spacesuits, optical lenses, and thermal blankets, causing numerous problems. Apollo mission spacesuits were damaged by abrasive lunar dust, and several astronauts noted that Moon dust was resistant to cleaning efforts; even vigorous brushing could not remove it. Mission documents from



Astronaut and geologist Dr. Harrison "Jack" Schmitt collects a soil sample during an Apollo 17 EVA. Credits: NASA

## Drilling on the Moon

As NASA travels to the Moon and beyond, there is a plan to put in place a sustainable infrastructure. This will allow for the exploration and study of more of the Moon. Astronauts will live and work in space for longer periods of time, which means that their access to supplies will be less immediate. But what if we could generate products from local materials that are on the Moon's surface? This practice is called **in-situ resource utilization** (ISRU).

Before Artemis astronauts land on the Moon, robots will scout the surface and collect information about the South Pole. The Polar Resources Ice Mining Experiment-1 (PRIME-1) will be the first in-situ resource utilization demonstration on the Moon. The data from PRIME-1 will help scientists understand in-situ resources and will help NASA's search for water on the Moon poles. PRIME-1 will help identify and assess the abundance and quality of water in an area expected to contain ice.

the six Apollo missions that landed on the lunar surface have been studied to catalog the effects of lunar dust on Extra-Vehicular Activity (EVA) systems, primarily the Apollo surface space suit. It was found that the effects could be sorted into nine categories: vision obscuration, false instrument readings, dust coating and contamination, loss of traction, clogging of mechanisms, abrasion, thermal control problems, seal failures, and inhalation and irritation. Although simple dust mitigation measures were sufficient to mitigate some of the problems (i.e., loss of traction) it was found that these measures were ineffective to mitigate many of the more serious problems (i.e., clogging, abrasion, diminished heat rejection). The severity of the dust problems was consistently underestimated by ground tests, indicating a need to develop better simulation facilities and procedures.

Fortunately, today NASA is exploring use of non-contact, electrostatic, dust-charging technology to protect the Agency's important space assets without restricting mission parameters. NASA's Artemis program will develop extensive resources on the Moon starting in 2024 and will require advanced technologies to enable a sustained lunar presence. Mitigation of lunar dust adhesion will be central to these efforts and to Artemis's success. However, lunar dust exhibits several characteristics that make it difficult to remove. For example, unlike Earth, the Moon does not have an atmosphere and magnetic field to protect its surface from impacts and solar radiation. The solar wind can electrically charge dust particles on the Moon, causing the charged particles to stick to each other and to other surfaces. In addition, lunar dust particles are very jagged and rough, which also increases their "sticking power." In the first lesson of this guide, students will identify the properties of lunar dust that make it a big problem on the lunar surface and use the engineering design process to create a dust mitigation device.



An artist's concept of the completed design of NASA's Volatiles Investigating Polar Exploration Rover, or VIPER. Credits: NASA/Daniel Rutter



After the PRIME-1 mission, the Volatiles Investigating Polar Exploration Rover (VIPER) will explore the relatively nearby but extreme environment of the Moon in search of ice and other potential resources. VIPER will directly look for water as a usable resource on the surface and subsurface of the Moon at varying depths and temperature conditions. VIPER's findings will inform future landing sites under Artemis by helping to determine locations where water and other resources can be harvested to support a long-term presence on the Moon.

VIPER's instruments all use spectrometers, scientific tools that look at light emitted or absorbed by materials to help identify their composition. The Neutron Spectrometer System (NSS) will indirectly detect potential water present in soil. The Regolith and Ice Drilling Exploring New Terrains (TRIDENT) will dig up soil cuttings from as much as three feet below the lunar surface. The Near-Infrared Volatiles Spectrometer System (NIRVSS) can tell the nature of hydrogen in the lunar soil. The Mass Spectrometer Observing Lunar Operations (MSolo) will assess the gases in the environment after touchdown to understand which ones are from the lunar surface and which are introduced by the lander itself. All the instruments work together to accomplish the mission's goal of prospecting for resources like water on the Moon. In the second activity of this guide, students will be challenged to compare the properties of ice to simulated icy-regolith on the Moon's south pole and design and build a drill bot that will be able to drill through simulated **icy-regolith**.

## Print a Lunar Habitat

In-Situ Resource Utilization (ISRU) can also be used on a much larger scale. The infrastructure required for a base to support sustained missions on the lunar surface will involve large scale construction projects. Large storage facilities will need to be built that will contain materials and resources harvested and produced on the Moon. Landing pads and roads will need to be constructed to mitigate the abrasive **regolith** that could be blown around during launches and landings and picked up through general transportation. Finally, habitats would need to be constructed that would not only provide the space needed for astronauts to live and work, but also provide safety from the constant bombardment of solar and cosmic radiation.

It would be virtually impossible to transport from Earth the resources needed to build this infrastructure. Instead, NASA and its partners have been developing ways to use lunar regolith as a basis for creating concrete-like material on the Moon. Turning this lunar concrete into structures will be accomplished by new additive manufacturing techniques. NASA partners are already working on the architectural designs for a lunar base camp and developing the automated 3D printers that will be used on the lunar surface to create them. These technologies are being tested in a large vacuum chamber using lunar simulant (i.e., simulated lunar regolith) to closely mirror the conditions of the lunar surface. In the third activity, the students will understand the necessity of ISRU and design and construct a model lunar habitat using simulated lunar concrete in an additive manufacturing process.

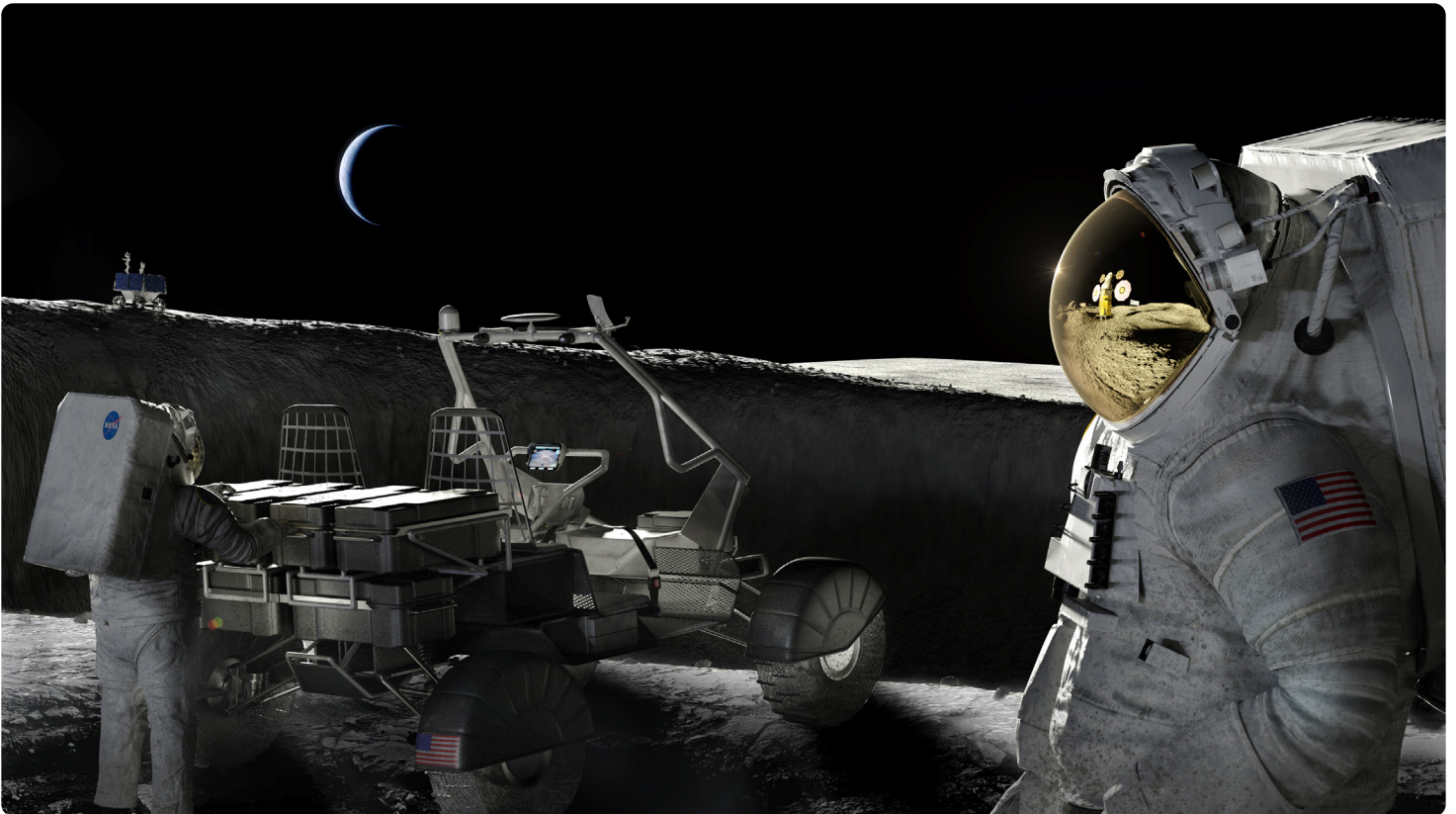


Team AI SpaceFactory's printer autonomously inserts a window into their 3D-printed subscale habitat structure at NASA's 3D-Printed Habitat Challenge, held at the Caterpillar Edwards Demonstration & Learning Center in Edwards, Illinois, May 1-4, 2019 Credits: NASA

## Extract, Pack, Transport

Many discoveries were made about the Moon and the history of our Solar System during the Apollo missions. Much of this knowledge comes from the rock samples the astronauts brought back with them from the Moon. Before their missions, the astronauts went through training to recognize different types of rocks and their significance. NASA's vision for space exploration calls for a return to the Moon before going to Mars and beyond. We'll learn how to "live off the land" by making oxygen and rocket propellants, also known as cryogenic propellants, and we'll be testing new technologies and operations. Cryogenic propellants must be stored at a constant temperature to prevent fuel loss due to "boil off." What is "boil off?" Since the Sun is heating the storage facility, the cold liquid wants to expand. Boil off is the vaporization of a liquid when it is being heated by its natural surroundings. On Earth, at normal room temperatures, this would be called evaporation. But in space, where the atmospheric pressure is different and

the fuel is stored at such cold temperatures, it turns into a vapor and is vented into space to prevent the storage facility from exploding. Why are cryogenic propellants a benefit to spaceflight? They dramatically increase the amount of the energy density of the propellant and the efficiency of the engines. As NASA seeks paths for human space exploration of multiple potential destinations such as the Moon, asteroids, the Lagrange points, Mars, and beyond, high-performance and highly efficient technologies are crucial. Living and working on the Moon will be a test run for living and working on Mars and beyond. In the last lesson of this guide, you will locate and simulate the mining of **ilmenite**, a mineral composed of iron and titanium oxide, which is a major resource for its oxygen on the surface of the Moon. You will then collect the oxygen that is extracted from the ilmenite and be challenged to build a cold storage and transfer system to store and safely transfer the fuel to a spacecraft.



Artist's rendering of astronauts conducting science and exploration activities on the lunar surface. Credits: NASA

# Activity One: Electrostatic Moon Duster

## EDUCATOR NOTES

### Learning Objectives

Students will

- Identify the properties of lunar dust that make it so problematic
- Develop a dust mitigation prototype given NASA's design criteria and constraints
- Measure the extent of electrostatic fields using a homemade device

### Challenge Overview

In this activity, students explore the engineering design process as if they were actual engineers working with NASA's Dust Mitigation engineering team. In this challenge, students will research, design, build, and test a lunar dust mitigation device.

### Suggested Pacing

60 to 90 minutes

## National STEM Standards

Science and Engineering (NGSS)	
<p><b>Disciplinary Core Ideas</b></p> <ul style="list-style-type: none"> <li>• <b>MS-ETS1-2 Engineering Design</b> Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.</li> <li>• <b>MS-ETS1-4 Engineering Design</b> Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.</li> <li>• <b>MS-PS2-3. Motion and Stability: Forces and Interactions</b> Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.</li> <li>• <b>MS-PS2-5 Motion and Stability: Forces and Interactions</b> Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.</li> </ul> <p><b>Crosscutting Concepts</b></p> <ul style="list-style-type: none"> <li>• Cause and Effect</li> </ul>	<p><b>Science and Engineering Practices</b></p> <ul style="list-style-type: none"> <li>• Constructing Explanations and Designing Solutions: Apply scientific ideas or principles to design an object, tool, process, or system.</li> <li>• 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.</li> <li>• Engaging in Argument from Evidence: Argumentation is the process by which explanations and solutions are reached.</li> <li>• 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.</li> </ul>
Technology (ISTE)	
<p><b>Standards for Students</b></p> <ul style="list-style-type: none"> <li>• 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.</li> <li>• Innovative Designer: Students use a variety of technologies within a design process to identify and solve problems by creating new, useful, or imaginative solutions.</li> </ul>	<p><b>Standards for Students (continued)</b></p> <ul style="list-style-type: none"> <li>• Global Collaborator: Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally.</li> </ul>
Mathematics (CCSS)	
<p><b>Mathematical Practices</b></p> <ul style="list-style-type: none"> <li>• <b>MP.2 Reason abstractly and quantitatively.</b> (MS-ETS1-4)</li> </ul>	

### Challenge Preparation

- Read the Introduction and Background section for this guide and the Educator Notes for this activity
- Have videos cued up for introduction of the challenge
- Prepare the suggested whole class demonstrations – regolith formation demonstration and electrostatic demonstration
- Group students into teams of two to four. Consider assigning roles and tasks to individual students within the team. See the Teamwork section at the beginning of the guide for suggestions.



- Gather materials needed to complete the challenge
- Create a “lunar testbed” for students to practice collecting regolith simulant. This could be a small pan or plastic bowl filled with regolith simulant (e.g., salt, wheat flour, packing peanuts, baking powder, QUIKRETE®, glitter)
  - **Salt Safety Data Sheet:**
    - ♦ [www.intrepidpotash.com/wp-content/uploads/2017/02/Carlsbad-Salt-SDS-3-13-2017-.pdf](http://www.intrepidpotash.com/wp-content/uploads/2017/02/Carlsbad-Salt-SDS-3-13-2017-.pdf)
  - **Wheat flour Safety Data Sheet:**
    - ♦ <http://s3.amazonaws.com/media.agricharts.com/sites/1846/Flour/SDS%20All%20Purpose%20Wheat%20Flour%20CO-EHS-1512-03.pdf>
  - **Baking powder Safety Data Sheet:**
    - ♦ <http://lkstevens-wa.safeschoolssds.com/document/repo/9d575b2d-3d18-449d-8d06-d74d75f411dc>
  - **QUIKRETE® safety data sheet:**
    - ♦ [www.quikrete.com/pdfs/msds-e-drypackagedportlandcement.pdf](http://www.quikrete.com/pdfs/msds-e-drypackagedportlandcement.pdf)
- Print one student handout for each team
- Review “The Lunar Regolith” Science Paper by Planetary Scientist Sarah Noble : <https://ntrs.nasa.gov/api/citations/20090026015/downloads/20090026015.pdf> *Note: The paper above is at a higher reading level, if used please help students navigate this text.*

**NOTE:** It’s suggested that, prior to this lesson, the educator might conduct a lesson on static electricity and have the groups build an electroscope (i.e., a device that detects if there is an electrical charge and how big the charge is).

## Materials

- One student handout per team
- Scratch paper and writing utensils
- Scotch tape for electrostatic demonstration
- Computers/devices with internet access or fact sheet handout for research
- Simulant for the lunar dust (e.g., salt, wheat flour, packing peanuts, baking powder, QUIKRETE®, glitter)
- Electrostatic charge creator: The following materials tend to give up electrons when brought in contact with other materials. That means they will have an increase of positive (+) charges. (e.g., Air, dry human skin, leather, fur, Styrofoam plates, wool on PVC, comb, glass rod, human hair, nylon, latex balloons)
- The following materials tend to attract electrons when brought in contact with other materials. (e.g. Wood, amber, hard rubber (comb), nickel, copper, brass, sliver, polyester, Styrofoam, saran wrap, scotch tape)
- Analytical balance: These are typically suitable for masses of 0.1mg up to 200g. They are more precise than precision balances but can’t bear as much load.

## Materials for Optional Electroscope

*Note: Items to design an electroscope (i.e., small plastic bottle with a narrow neck, scissors, pliers with a wire cutter, copper wire, aluminum foil, sponge, foam tray, piece of felt, optionally a hole punch)*

## Safety

- Ensure students are practicing safe cutting techniques and scissor handling when building their tools
- Ensure students carefully support the piece being cut and are careful with placement of supporting hand
- Students should avoid moving around the room with scissors
- Ensure students use caution and wear protective goggles when building and testing the tool design
- Ensure students wash hands after handling simulant regolith
- Ensure students minimize stirring up dust from the flour/powder. Keep dust to a minimum.
- Ensure students review the Safety Data Sheet for the simulant regolith
- If you have any student with a latex allergy, have allergic students wear non-latex plastic gloves and inflate the balloons with a balloon pump (or form small teams and give the balloon handling part of the activity to non-allergic students).

## Introduce the Challenge

- Provide context for this activity using the Introduction and Background section in this guide
- How do we know so much about the Moon? Specifically, lunar dust (regolith)? Give students time to share their thoughts.
- Share the following videos:
  - "Lunar and Meteorite Sample Disk Program": <https://youtu.be/xYMuQPWvufg> (share the first 2:45 min)
  - "The Best Gift of All – A Box of Moon Soil": <https://Moon.nasa.gov/resources/393/the-best-gift-of-all-a-box-of-Moon-soil/> (1:23)
  - "Lunar/Crater Surface – Dust Mitigation System": NASA 360 <https://youtu.be/xXFmsZTH4C8> (1:20)
- Explain the challenge to students:
  - Each team will use the available materials to build a functioning dust mitigation removal tool
  - The tool must be designed to mitigate as much lunar dust simulant as possible
  - It may be helpful to provide the Rubric for Engineering Design Process (Appendix A) to teams prior to building
  - After teams have tested and perfected their working dust mitigation tool, they will develop a user manual or instruction guide for the tool. Various platforms, such as a brochure, poster, or digital presentation, can be used for their manual.
- See the References and Resources at the end of the Educator Notes for further information on lunar dust mitigation tools if students need more ideas about the tools they will be inventing

Criteria	Constraints
Use of tool must not require more than one person.	Students must only use materials supplied by the educator.
Teams must create a presentation or user manual about the use of their new tool.	Teams will only have 5 seconds to remove simulant from their helmet.
Document the mass of regolith simulant before and after tool use.	

## Facilitate the Challenge

### ?ASK

NASA's Artemis program will develop extensive resources on the Moon starting in 2024 and will require advanced technologies to enable a sustained lunar presence. Mitigation of lunar dust adhesion will be central to these efforts and to Artemis's success.

- Have students buddy read "Dust: An Out-of-This World Problem" and answer the comprehension questions:
  - [www.nasa.gov/feature/glenn/2021/dust-an-out-of-this-world-problem](http://www.nasa.gov/feature/glenn/2021/dust-an-out-of-this-world-problem)

Conduct the following demonstrations

- **Regolith Formation Demo:**
  - [www.nasa.gov/pdf/180567main\\_ETM.Regolith.Formation.pdf](http://www.nasa.gov/pdf/180567main_ETM.Regolith.Formation.pdf) (To create food substitute, use dirt or red clay like the type from baseball fields) **NOTE:** *When food is used in the classroom, please keep in mind food insecurities or allergies. We want to create a more equitable and inclusive learning environment for all students, regardless of their socio-economic background or food access.*
- **Electrostatic Demonstrations** pg. 9-10 (labeled pg. 5-6): Sticky Tape Static Electricity: (Optional)
  - <https://www.nasa.gov/stem-content/imageticospace-sticky-tape-static-electricity-activity/>

Have students research moon dust and electromagnetic properties. Have students talk in teams about the comprehension questions:

- How did lunar dust (regolith) form?
- Why is lunar dust (regolith) such a huge problem?
- What are some possible solutions to this problem?

## **IMAGINE**

Ask students:

- What do you think might be a solution to the dust problem?
- Can your team develop a strategy to mitigate this problem for future work on the Moon?
- What items would you need to build this tool?

## **PLAN**

Have each team member sketch a design for a dust mitigation tool

- Share the following guidelines for each sketch:
  - Label each major part of the tool
  - State the purpose of the tool
  - List the materials the tool will be made from
- Explain that the final design must incorporate at least one design idea from each team member

## **CREATE**

- Be sure to confer with students during the activity.
- Allow teams at least 30 minutes to construct their new tools using the materials provided and the sketches they have created
- Each team's new tool should be a dust mitigation device that can be used by a single astronaut
- Ensure the teams are creating a tool that can be tested multiple times

## **TEST**

- Now that teams have created their own dust mitigation tool, allow them some time to explore the lunar testbed and experiment with their new tools
- Ensure teams record mass 1 of helmet (Latex Balloon or Styrofoam plate alone).
- After the regolith simulant is added using electrostatic force (by rubbing their "helmet" in the regolith simulant to make the electrostatic force and make the regolith stick), find the new mass, mass 2 (Styrofoam plate plus additional regolith simulant).
- Have the teams use their tool and dust mitigating procedures to remove as much regolith simulant in 5 seconds or less

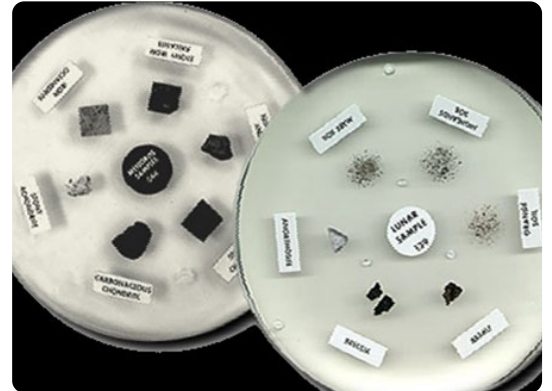
## **IMPROVE**

This phase of the engineering design process is generally intuitive to students. However, some students may need a little help in troubleshooting their designs if failures occur. Be sure to visit and spend time with each team and ask probing questions:

- Is the design working as expected? What can you do to improve your design?
- Where are the weaknesses in the design, and what can be done to strengthen the tool?

## Share With Students

### **Brain Booster**

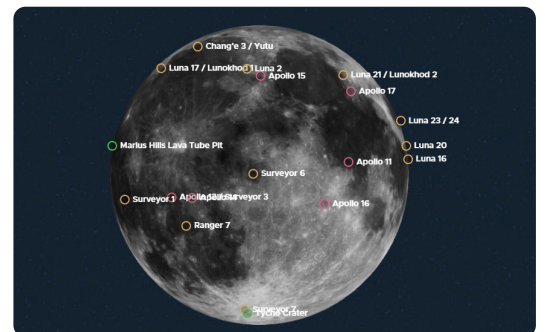


Picture of lunar and meteorite disk

The Lunar and Meteorite Sample Disk Program is intended for K-12 classrooms, or qualified museums and libraries.

Learn more: <https://ares.jsc.nasa.gov/interaction/lmdp/>

### **On Location**



Picture of interactive Moon and places explored

Earth's Moon is the only place beyond Earth where humans have set foot. Yet we still have so many unanswered questions about it, and this is one of the reasons NASA is going back with the Artemis Program. Explore more using this interactive site.

Learn more: <https://solarsystem.nasa.gov/moons/earths-moon/in-depth/>



## SHARE

- Have students discuss the following questions with their team:
  - 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 tool? Explain.
  - How were you able to improve your tool during the redesign phase? What design changes did you make, and how did they improve your tool's performance?
  - What was something about another team's model that impressed you?
- To share their dust mitigation tool with others, teams should develop an instruction manual for the tool using their choice of a variety of platforms, such as posters, brochures, digital presentations, and notebooks
  - Optional: Have student groups share the tool they have invented with other classes or grade levels
  - Optional: Share student results on social media using #NextGenSTEM. Be sure to include the module and activity name

## Extensions

- Have the students interact with Classifying Moon Rocks website: <https://ares.jsc.nasa.gov/engagement/interactives/classifying%20moon%20rocks/story.html>
- Tune into Kennedy Space Centers Lunabotics Competition: [www.nasa.gov/offices/education/centers/kennedy/technology/nasarmc.html](http://www.nasa.gov/offices/education/centers/kennedy/technology/nasarmc.html)

## References and Resources

- New "Moon Duster" will help clean NASA assets in space | Science Mission Directorate: <https://science.nasa.gov/technology/technology-highlights/new-moon-duster-will-help-clean-nasa-assets-in-space#:~:text=A%20team%20at%20NASA%2FJet,and%20spacesuits%20on%20the%20Moo>
- Electrostatics and Surface Physics Lab: [www.nasa.gov/content/electrostatics-and-surface-physics-laboratory](http://www.nasa.gov/content/electrostatics-and-surface-physics-laboratory)

# Activity One: Electrostatic Moon Duster

## STUDENT HANDOUT

### Your Challenge

In this challenge your team will research, design, build, and test a lunar dust mitigation device.

Criteria	Constraints
Use of tool must not require more than one person.	Teams must only use materials supplied by the educator.
Teams must create a presentation or user manual about the use of their new tool.	Teams will only have 5 seconds to remove simulant from their helmet.
Document the mass of regolith simulant before and after tool use.	

### ? ASK

As a team, buddy read “Dust: An Out-of-This World Problem” and answer the comprehension questions. [www.nasa.gov/feature/glenn/2021/dust-an-out-of-this-world-problem](http://www.nasa.gov/feature/glenn/2021/dust-an-out-of-this-world-problem)

- How did lunar dust (regolith) form?
- Why is lunar dust (regolith) such a huge problem?
- What are some possible solutions to this problem?
- Watch the educator’s Regolith formation Demonstration and Electrostatic Demonstration



### IMAGINE

- What do you think might be a solution to the dust problem?
- Can your team develop a strategy to mitigate this problem for future work on the Moon?
- What items would you need to build this tool?



### PLAN

Have each team member sketch a design for a dust mitigation tool

- Share the following guidelines for each sketch:
  - Label each major part of the tool
  - State the purpose of the tool
  - List the materials the tool will be made from
- The final design must incorporate at least one design idea from each team member



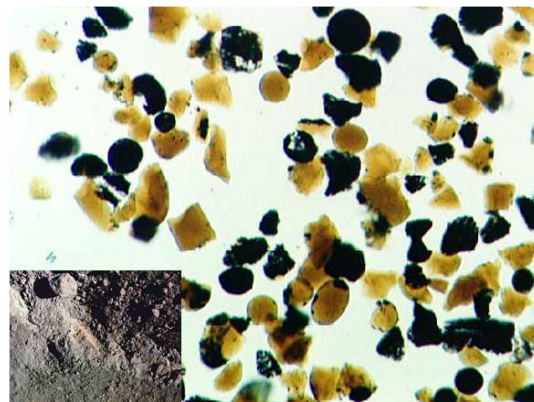
### CREATE

- Your team will have at least 30 minutes to construct your new tools using the materials provided and the sketches you have created
- Your team’s new tool should be a dust mitigation device that can be used by a single astronaut
- Be sure to create a tool that can be tested multiple times

## Share With Students



### FUN FACT!



Strange Orange Soil on the Moon; Credits: Apollo 17 Crew, NASA  
How did orange soil appear on the Moon?

Learn more: <https://apod.nasa.gov/apod/ap010523.html>



### CAREER CORNER



Sarah Noble - Planetary Geologist

NASA Solar System Exploration. Credits: NASA

"When I look up at the Moon it looks different to me, not just something that hangs in the sky, but a real place made of real rocks and dirt."

Learn more: <https://solarsystem.nasa.gov/people/1740/sarah-noble/>

## TEST

- Now that your team has created a dust mitigation tool, explore the lunar testbed and experiment with your new tool
- Be sure to record mass 1 of helmet (Latex Balloon or Styrofoam plate alone)
- After the regolith simulant is added using electrostatic force, find the new mass, mass 2 (balloon plus additional regolith)
- Use your tool and dust mitigating procedures to remove as much regolith simulant as you can in 5 seconds or less

## IMPROVE

This phase of the engineering design process is generally intuitive. Let your teacher know if you will need extra help in troubleshooting your design if failures occur. Ask yourselves these questions:

- Is the design working as expected?
- What can you do to improve your design?
- Where are the weaknesses in the design, and what can be done to strengthen the tool?

## SHARE

Your team should discuss the following 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 tool? Explain.
- How were you able to improve your tool during the redesign phase? What design changes did you make, and how did they improve your tool's performance?
- What was something about another team's model that impressed you?
- Optional: The above questions can be used as a written self-reflection for students.

Share your dust mitigation tool with others. You should develop an instruction manual for the tool using your choice of a variety of platforms, such as posters, brochures, digital presentations, and notebooks.



# Activity Two: Drilling on the Moon

## EDUCATOR NOTES

### Learning Objectives

Students will

- Compare and contrast the properties of ice to simulated icy-regolith on the Moon’s south pole
- Design and build a drill bot that will be able to drill through simulated icy-regolith

### Challenge Overview

Students will explore the properties of water, comparing ice to the icy-regolith found on the Moon. Students will then design a drill bot that will be able to drill through simulated icy-regolith to obtain in-situ resources needed for sustainability on the Moon.

### Suggested Pacing

90 minutes

## National STEM Standards

Science and Engineering (NGSS)	
<p><b>Disciplinary Core Ideas</b></p> <ul style="list-style-type: none"> <li>• <b>MS-ETS1-2 Engineering Design</b> Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.</li> <li>• <b>PS1.A: Structure and Properties of Matter</b> Different kinds of matter exist and many of them can either be a solid or liquid, depending on temperature.</li> </ul> <p><b>Crosscutting Concepts</b></p> <ul style="list-style-type: none"> <li>• <b>Cause and Effect:</b> Cause and effect relationships may be used to predict phenomena in natural or designed systems.</li> <li>• <b>Influence of Science, Engineering and Technology on Society and the Natural World:</b> The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by the differences in such factors as climate, natural resources, and economic conditions.</li> </ul>	<p><b>Science and Engineering Practices</b></p> <ul style="list-style-type: none"> <li>• <b>Constructing Explanations and Designing Solutions:</b> Apply scientific ideas or principles to design an object, tool, process, or system.</li> <li>• <b>Asking Questions and Defining Problems:</b> 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.</li> <li>• <b>Engaging in Argument from Evidence:</b> Argumentation is the process by which explanations and solutions are reached.</li> <li>• <b>Obtaining, Evaluating, and Communicating Information:</b> 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.</li> </ul>
Technology (ISTE)	
<p><b>Standards for Students</b></p> <ul style="list-style-type: none"> <li>• <b>Innovative Designer:</b> Students use a variety of technologies within a design process to identify and solve problems by creating new, useful, or imaginative solutions</li> </ul>	<p><b>Standards for Students (continued)</b></p> <ul style="list-style-type: none"> <li>• <b>Global Collaborator:</b> Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally</li> </ul>

### Challenge Preparation

- Read the Introduction and Background section for this guide and the Educator Notes for this activity
- Print one student handout for each team

### Materials

- Battery powered toothbrush (1 per team)  
*Note to educator: You can check your local discount stores for this item.*
- Foam noodle or plastic cup
- Rubber bands
- Electrical tape
- Metal washers or pennies
- Plastic spoon
- Craft sticks
- Chop sticks
- Push pin
- Paper clips

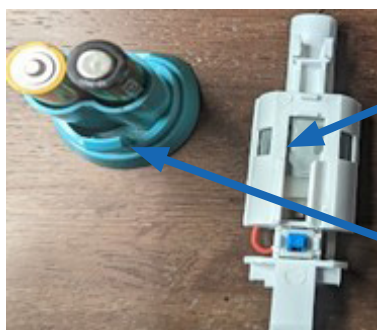
## Directions for assembling the drill bot

1. Assemble all supplies needed.
2. Remove the bottom end of the electric powered toothbrush. Remove the battery compartment. The motor will be underneath the battery compartment. Do not use a sharp object to pop the motor loose. Use eye protection for this step.



Motor to be removed

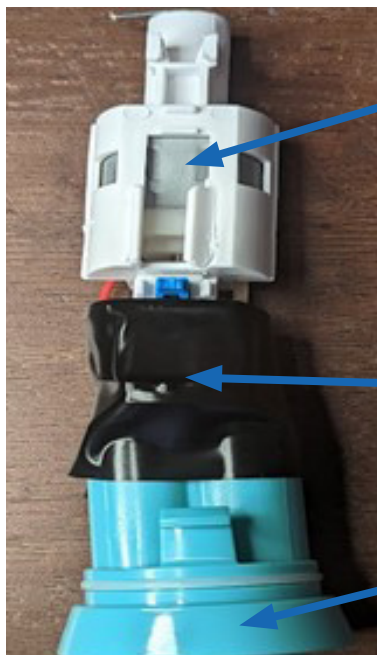
3. There will be 2 separate compartments that will need to be taped together with electrical tape for a complete motor.



Motor

Battery compartment

*Note: Each toothbrush motor looks different, so the motor removed may not look like the one above.*



Motor

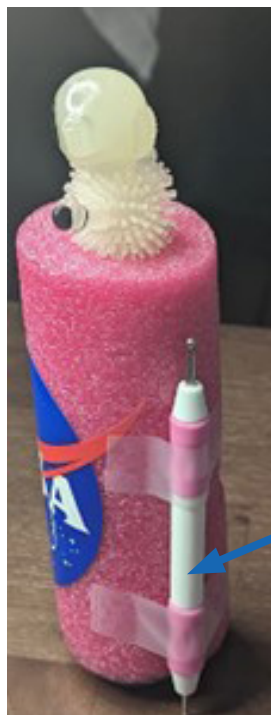
Electrical tape

Battery compartment

4. Once the motor and battery compartment are taped together using electrical tape, insert the two parts into your noodle. *Note: It is easier to cut a small hole in the front of the noodle to allow access to the on/off switch for the motor. All exposed connections must be taped. The power must be off and completely taped with electrical tape to cover all exposed wires and conductive (metal) parts and exposed connections. All students must have the educator review their "build" before it is used to ensure all exposed conductive parts have been taped.*



5. Test to make sure that the drill bot can move easily before adding the drill or any decorations.
6. Add your drill and test using the water ice provided. The students will decide what their drill will be (e.g., plastic spoon, craft stick, etc.).



Drill

Here are some examples of problems students may encounter and some suggestions:

- The drill bot moves too fast around the icy-regolith
  - The student should consider adding some weight (washers or pennies may be used). Students need to determine where the weight should be added to make the drill bot more stable.
- The motor is not rotating freely
  - The student can enlarge the hole of the foam noodle to allow for more vibration for movement



## Materials for simulated icy-regolith

- Container (ice cube tray, plastic cup, etc.)
- Sand
- Water

### Preparation for Icy-regolith

You will fill half the container with water and half with sand and place container in the freezer overnight. If you are using an ice tray, it is easier to use a teaspoon or tablespoon as a scoop to fill the tray halfway up with sand, then fill to the top with water and place in the freezer (preferably overnight). Simulated icy-regolith taken out of the freezer must be used immediately.

## Safety

Ensure that

- Students wear eye protection when building and drilling the simulated icy-regolith
- Students practice safe cutting techniques when building and testing their drill. Carefully support the piece being cut. Be careful with placement of non-scissor holding hand.
- Students avoid moving about the room with scissors or other sharp objects
- Students tape with electrical tape the terminal ends of the batteries when they are not stored in their original packaging
- Students tape all bare wire and any exposed electrical connections with electrical tape. Students must review their build with the educator before turning it on.

## Introduce the Challenge

- Provide context for this activity using the Introduction and Background section in this guide. Discuss the importance of drilling on the Moon.
- Share the video "The Polar Resources Ice Mining Experiment-1 (PRIME-1)." <https://youtu.be/8WWUCusBHKY>
- 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 to each team.
- Explain the challenge to students.
  - Each team will be designing a drill that will be able to penetrate the simulated icy-regolith that have been given to you by your educator.
  - The drill must be able to obtain enough sample that can be transported.
  - Teams can only use the materials available to them.

Criteria	Constraints
Students cannot use their hands to move the drill bot.	Students must only use the materials provided by the educator.
Students cannot apply objects other than what is provided to add weight on their drill bot.	Students must not apply any additional weight to the drill.

## Facilitate the Challenge

### ASK

- Share this question with students: What is the difference between ice and icy-regolith?
- Have students brainstorm for a few minutes all the properties that they know about water and all the properties they know about ice.

Give teams 4-6 ice cubes and 4-6 of the icy-regolith ice cubes (water and sand mixture). Tell students that they are going to compare how ice cubes and the icy-regolith melt under different conditions. *Note: This can also be done as a classroom demonstration, having teams just do one of the conditions below. You may also want students to time how long it takes the ice cubes to melt.*
- Ask students to predict what will happen to the ice and icy-regolith under the following conditions: (Icy-regolith

cubes will melt the faster than regular ice cubes in each of the conditions below, but especially in the hot water.)

- Both placed in a dish of room temperature water
- Both placed in a dish of hot water
- Both placed under flowing room temperature water
- Both placed under flowing hot water
- Ask students the following questions:
  - Which ice cubes melted fastest? Icy-regolith or ice?
  - Were your predictions and results similar? Different?

## IMAGINE

- Share the video “NASA’s Break the Ice Challenge” <https://youtu.be/wXS0uCLisu8>
- Allow students to see all the materials before building their drill bot
- Have students create their own individual sketches of their drill, and then the group, as a whole, will incorporate the strengths of each design into one final idea

## PLAN

- Each team will now create one sketch of their drill bot design, complete with labels and descriptions of the materials used. Have students keep in mind the following questions:
  - How will you ensure that the drilling device will not break?
  - What mechanism will you use to ensure that the drill is breaking up the water ice?
- After reviewing each group’s drawing, allow students to retrieve the needed material to construct their drill bot

## CREATE

- Be sure to confer with students during the activity.
- Have teams construct their drill bot
- Their drill bot must use only one device for drilling (e.g. Chopsticks, craft sticks, paper clip, etc.)

## TEST

- Now that students have created their own drill bot, allow them to test their drill bot on the simulated icy-regolith
- Ensure that teams are not adding any additional weight to their drill bot and are not using their hands

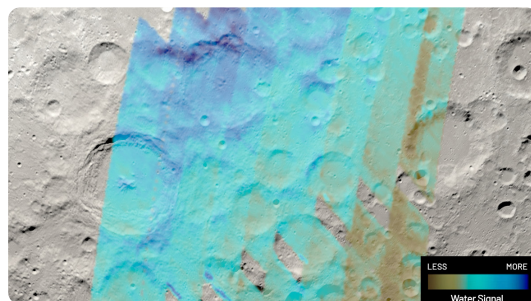
## IMPROVE

- Now that teams have built and tested their drill bot, they may need some help in troubleshooting their designs if failures occur. Be sure to visit and spend some time with each team and ask the following probing questions:
  - Is the design working as expected? What can be improved to change it?
  - What are the weaknesses in the design, and what can be done to overcome the weaknesses?
  - Do you think additional weight needs to be added to the drill bot? If so, where would you add it?

## Share With Students



### Brain Booster



First detailed wide-area map of water on the Moon.

Did you know that scientists thought there was water on the Moon in 1645? Discover the history of how scientists discovered water on the Moon in an interactive timeline.

Learn more: <https://moon.nasa.gov/inside-and-out/water-on-the-moon/>



### On Location

VIPER, Volatiles Investigating Polar Exploration Rover, will travel on four hollow wheels with ribs for traction in powdery, abrasive Moon dust. So how did scientists test VIPER? The team used a dust chamber at NASA’s Johnson Space Center in Houston and the Simulated Lunar Observation Laboratory (SLOPE) at NASA’s Glenn Research Center.

Learn more:  
<https://ares.jsc.nasa.gov/projects/simulants/dust-testing-facilities/johnson-space-center.html> (Johnson Dust Testing)  
[www.nasa.gov/specials/slope360/#](http://www.nasa.gov/specials/slope360/#) (Slope Lab Tour)

## SHARE

- Engage students with the following discussion questions:
  - What are some of the difficulties your team faced during the initial design and build process, and how did you overcome them?
  - Were you surprised at how difficult it was to drill through simulated icy-regolith?
  - What was something about another team's model that impressed you?
  - How were you able to improve your design through the improve phase? What changes did you make and how did they improve your bot's performance?
- Optional: The above questions can be used as a written self-reflection for students
- Optional: Have student groups share the drill bot they have invented with other classes or grade levels
- Optional: Share student results on social media using #NextGenSTEM. Be sure to include the module and activity name

## Extensions

- Have students design and create a drill using simple machines or a robotics kit
- Explore the Break the Ice Challenge: <https://breaktheicechallenge.com/>
- "Explore Polar Resources Ice Mining Experiment-1 (PRIME-1)": [www.nasa.gov/directorates/spacetech/game\\_changing\\_development/projects/PRIME-1](http://www.nasa.gov/directorates/spacetech/game_changing_development/projects/PRIME-1)

## Reference

- Melting Ice Experiment: [www.jpl.nasa.gov/edu/teach/activity/melting-ice-experiment/](http://www.jpl.nasa.gov/edu/teach/activity/melting-ice-experiment/)



# Activity Two: Drilling on the Moon

## STUDENT HANDOUT

### Your Challenge

In this challenge, you will be working in teams to construct a drill bot that is able to drill through icy-regolith.

Criteria	Constraints
Students cannot use their hands to move the drill bot.	Students must only use the materials provided by the educator.
Students cannot apply objects other than what is provided to add weight on their drill bot.	Students must not apply any additional weight to the drill.

### ? ASK

- You will be performing an experiment to see the difference between ice and the icy-regolith found on the Moon
- Predict what will happen to the ice and icy-regolith under the following conditions:
  - Both placed in a dish of room temperature water
  - Both placed in a dish of hot water
  - Both placed under flowing room temperature water
  - Both placed under flowing hot water
- Perform the experiment and notice differences between how ice and icy-regolith melt
- Answer the following questions:
  - Which ice cubes melted fastest? Icy-regolith or ice?
  - Were your predictions and results similar? Different?

### 💡 IMAGINE

- As a team, take some time to discuss how you want to construct your drill bot
- Have each member sketch their own idea; then the group can incorporate the strength of each design
- Make sure you see all the materials before sketching your drill bot

### 📎 PLAN

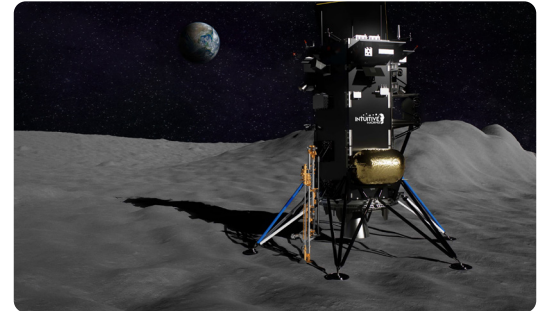
- You will now create one sketch of your drill bot design, complete with labels and descriptions of the materials being used. Keep in mind the following questions:
  - How will you ensure that the drilling device will not break?
  - What mechanism will you use to ensure that the drill is breaking up the icy-regolith?
- After your educator approves your sketch, retrieve the materials needed to construct your drill bot

## Share With Students



### FUN FACT!

What do you think about when you hear PRIME-1? The Polar Resources Ice Mining Experiment-1 (PRIME-1) will be the first in-situ resource demonstration on the Moon. NASA will robotically sample and analyze ice from below the surface.



An artist's rendering of NASA's Polar Resources Ice Mining Experiment-1 (PRIME-1).

Learn more: [www.nasa.gov/directorates/spacetech/game\\_changing\\_development/projects/PRIME-1](http://www.nasa.gov/directorates/spacetech/game_changing_development/projects/PRIME-1)



### CAREER CORNER



Jacqueline Quinn. Credits: NASA

Jacqueline Quinn is the project manager for Polar Resources Ice Mining Experiment-1 (PRIME-1), which is comprised of the Mass

Spectrometer Observing Lunar Operations (MSolo) and The Regolith and Ice Drill for Exploring New Terrains. MSolo will assess gases in the environment after Volatiles Investigating Polar Exploration Rover (VIPER) touches down on the Moon. The TRIDENT will dig as much as 3 feet below the lunar surface.

Learn more: [https://youtu.be/7zkzIWeXk\\_M](https://youtu.be/7zkzIWeXk_M)

## **CREATE**

- Construct your drill bot and make sure that everyone on your team can help
- Make sure the drill bot contains only one device for drilling (e.g. chopsticks, craft sticks, paper clip, etc.)

## **TEST**

Now it is time to test your drill bot.

- You will see if your drill bot can drill through the icy-regolith and obtain a small sample
- Ensure that you are not adding any additional weight to your drill bot by using your hands

## **IMPROVE**

Now that you have built and tested your drill bot, you may need to improve it based on your results. Be sure to think about the following questions as you work to improve your design:

- Is the design working as expected? What can be improved to change it?
- What are the weaknesses in the design, and what can be done to overcome the weaknesses?
- Do you think additional weight needs to be added to the drill bot? If so, where would you add it?

## **SHARE**

Present your drill bot to the class; discuss any challenges your team faced and how you overcame those changes. Think about the following questions:

- What are some of the difficulties your team faced during the initial design and build process, and how did you overcome them?
- Were you surprised at how difficult it was to drill through simulated icy-regolith?
- What was something about another team's model that impressed you?
- How were you able to improve your design through the improve phase? What changes did you make and how did they improve your bot's performance?

# Activity Three: Print a Lunar Habitat

## EDUCATOR NOTES

### Learning Objectives

Students will

- Understand the necessity of in-situ resource utilization (ISRU) for supporting sustainable lunar surface exploration
- Design and construct a model lunar habitat using an additive manufacturing process with simulated lunar concrete

### Challenge Overview

In this challenge, students learn the importance of being able to use materials already available on the lunar surface in the construction of lunar base infrastructure. They will then design a lunar habitat and create a model of their design using a process that mimics 3D printing.

### Suggested Pacing

120 to 180 minutes total spread out over 3 to 4 days.

### National STEM Standards

Science and Engineering (NGSS)	
<p><b>Disciplinary Core Ideas</b></p> <ul style="list-style-type: none"><li>• <b>MS-ETS1-2 Engineering Design</b> Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.</li><li>• <b>MS-ETS1-4 Engineering Design</b> Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.</li></ul>	<p><b>Science and Engineering Practices</b></p> <ul style="list-style-type: none"><li>• <b>Constructing Explanations and Designing Solutions:</b> Apply scientific ideas or principles to design an object, tool, process, or system.</li><li>• <b>Engaging in Argument from Evidence:</b> Argumentation is the process by which explanations and solutions are reached.</li><li>• <b>Develop a model to generate data to test ideas about designed systems,</b> including those representing inputs and outputs.</li></ul>
Technology (ISTE)	
<p><b>Standards for Students</b></p> <ul style="list-style-type: none"><li>• <b>Innovative Designer:</b> Students use a variety of technologies within a design process to identify and solve problems by creating new, useful, or imaginative solutions</li></ul>	<p><b>Standards for Students (continued)</b></p> <ul style="list-style-type: none"><li>• <b>Global Collaborator:</b> Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally.</li></ul>

### Challenge Preparation

- Read the Introduction and Background section for this guide and the Educator Notes for this activity
- Print one student handout for each team
- Choose a recipe for your simulated lunar cement. Each team will likely need 4-6 cups of simulated cement to complete the activity. You can make it ahead of time, or have students help make it as part of the activity. If making it ahead of time, keep it sealed in plastic bags to keep it from drying prematurely. Two example recipes are given below, or you may research/create your own.
- Drywall Compound Based Cement
  - 4 cups of lightweight drywall compound
  - 1 cup of white glue or latex paint
  - Mix well until smooth
- Flour Based Cement
  - 3 cups of flour
  - 2 tablespoons of salt
  - 2 cups of warm water
  - 1 cup white glue
  - Mix well until smooth

### Materials

- One student handout per team
- Scratch paper and writing utensils

- Large sheet of sturdy cardboard per team (approx. 24 inches x 24 inches)
- Large disposable cake decorating bags
- Large bowls
- Sink
- Paper Towels
- Scissors
- Large spoons or spatulas
- Simulated lunar cement (see challenge preparation for recipes)
- Sand and or fine gravel
- Small latex or non-latex balloons
- Extra scraps of cardboard

## Safety

- Ensure students are mindful of any potential student allergies regarding the supplies used in this activity
- Ensure students wear eye protection when handling drywall compound and glue
- Ensure students wash hand if any drywall compound or glue gets on their hands
- Ensure students practice classroom safety while performing this activity and avoid creating slip hazards due to spills. Any floor areas that may get wet should be protected from foot traffic.
- Ensure students practice safe cutting techniques when using scissors and carefully support the piece being cut while using care on the placement of the hand not holding the scissors
- Ensure students avoid moving around the room with scissors or other sharp objects
- If you have any student with a latex allergy, wash the balloons before using. Have allergic students wear non-latex plastic gloves and inflate the balloons with a balloon pump (or form small teams and give the balloon handling part of the activity to non-allergic students).

## Introduce the Challenge

- Provide context for this activity using the Information and Background section in this guide:
  - Discuss how difficult it is to launch heavy materials into space and how it is orders of magnitude more difficult to transport them to the surface of the Moon. How does this make In-Situ Resource Utilization (ISRU) important?
  - Discuss additive manufacturing and how we are now able to use 3D printers to make items out of a variety of materials. Ask the students if they think something as large as a house could be 3D printed on the Moon.
- Share the video “Teams Build 3D-Printed Habitats for Moon and Mars”: [https://youtu.be/-HT\\_MhzYkus](https://youtu.be/-HT_MhzYkus) Tell the students that they will be challenged to design and print a much smaller scale lunar habitat.
- 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 to each team
- Explain the challenge to students:
  - Each team will be designing a habitat that can sustain a crew of four astronauts on the lunar surface
  - A 2D footprint of their design will be transferred onto a sheet of cardboard like a floor plan of a house
  - The size of the floor plan should not exceed 12x18 inches
  - Their 2D footprint will serve as the template for teams to 3D print their habitats using simulated lunar cement

Criteria	Constraints
Designs must contain necessary areas for a crew of four astronauts.	Simulated lunar cement cannot be applied by smearing or with any tool other than the frosting bag.
Design must fit on the cardboard sheet provided.	The size of the floor plan should not exceed 18x24 inches.
Must build the habitat by using 3D printing supplies provided by the teacher.	
May use inflated balloons or other items to support the roof of the structure as long as such items can be removed after structure dries.	



## Facilitate the Challenge

### ? ASK

- Share and discuss the following questions:
  - How much indoor space do you require to live?
  - What about your whole family?
  - What kind of separate spaces are needed in a house?
    - ♦ Possible answers: kitchen, bathroom, bedrooms, living room, etc.
  - If you had to downsize your living space, how could you minimize any of those separate spaces?
    - ♦ Possible answers: share bedrooms, sleep in living room, smaller kitchen/bathroom, etc.

### 💡 IMAGINE

- Have the students imagine they had to live and work in a habitat on the lunar surface in a team of four. Discuss the other types of spaces they would need in their habitat.
  - Possible answers: Laboratories, storage space, an airlock
- Remind students that they will be tasked with making a 3D printed model of a lunar habitat and that it must contain all the spaces needed for a crew of four astronauts to live and work in space
- Ask them to discuss what their design could look like. Remind them to consider the build process as part of their design. The whole structure must be 3D printed from the ground up, using the simulated lunar cement. Additional materials, such as an inflated balloon, may be used to support the roofs during construction, but such item(s) must be removed after the structure dries.

### ✂️ PLAN

- On sheets of paper, have each team draw plans of what their lunar habitat will look like. The drawing must include an exterior shot to show its architectural shape as well an interior floor plan to show the layout, with the purpose of each room labeled.

### 🔧 CREATE

- Using their interior floor plan as a guide, have each team transfer their floor plan onto a large sheet of cardboard. The cardboard should be large enough that each room will be clearly defined when the model is complete, but not so large that it wastes materials and is too flimsy to construct.
- If breaking this activity into several days, this would be a good place to pause the activity for the first day
- For the 3D printing portion of the activity, pass out to each team:
  - Their cardboard floor plan templates
  - Premade simulated lunar cement (or the ingredients to make it themselves)
  - A few cake decorating bags
  - Scissors
  - Spoon or spatula

## Share With Students



### Brain Booster



European Space Agency astronaut Alexander Gerst works on the MICS experiment aboard the International Space Station

The Microgravity Investigation of Cement Solidification (MICS) project allows the testing of cement solidification in microgravity environments aboard the International Space Station. They can even use centrifuges aboard the station to test the low environment conditions on the Moon and Mars.

Learn more: [www.youtube.com/watch?v=lsiyNZeUfUU&t=9s](https://www.youtube.com/watch?v=lsiyNZeUfUU&t=9s)



### On Location



Wide-angle view into the test chamber of the Space Environments Complex (SEC)

The Space Simulation Vacuum Chamber at NASA's Glenn Research Center is the world's largest vacuum Chamber. This facility allows NASA to test large pieces of equipment, including large-scale 3D printers, in an environment similar to that of the lunar surface.

Learn more: [www1.grc.nasa.gov/facilities/sec/](http://www1.grc.nasa.gov/facilities/sec/)

- Sand and or fine gravel
- Cardboard scraps
- First students will test their simulated lunar cement; then they will adjust the mixture to find the right consistency that works for them. You want the consistency to be thick enough to be stack layers on top of each other, but not too thick to squeeze from the bag.
  - Have the students spoon a small amount of simulated lunar cement into a cake decorating bag
  - They should cut just a small amount off the tip of the bag to make a small hole.
  - Have the students use scrap pieces of cardboard to practice extruding the simulated lunar cement in straight and curved lines as well as trying to stack lines on top of each other to build three-dimensional shapes
  - Invite the students to experiment with the consistency of their cement by adding sand and/or fine gravel to the mixture

*Note: Adding sand and/or fine gravel to the cement will make it stronger and thicker, similar to how adding aggregate strengthens concrete. Adding too much, though, may make it more difficult to squeeze the cement from the cake decorating bags.*

- Students may also experiment with the size of the hole in the tip of their cake decorating bags. A larger hole will extrude a thicker and wider layer of cement with each pass. Have the students be careful not to cut too much off. The ideal thickness will be between 0.5 and 0.75 cm (or about ¼ to ½ inches) thick.
- Once the teams have made the adjustments to their simulated lunar cement mixtures, they can begin building the walls of their habitats, following the floor plans they created. Encourage the students to try making consistent lines around the perimeter and any interior walls, making each pass blend into the one below it, and trying to stay as level as possible.
- Once the teams have reached the maximum heights of their walls, and before they begin to add their roofs, have them pause
- If breaking this activity into several days, this would be a good place to pause the activity for the day. Have the students seal up any remaining simulated lunar cement in plastic resealable plastic bags and clean their workstations. They should very carefully place their incomplete models in a safe place until it is time to resume the activity. Their current walls should start to dry overnight.
- When the teams are ready to resume their models, have them carefully return them to their workstations
- Pass out the supplies needed to extrude the simulated lunar cement, and pass out small balloons and scraps of cardboard
- Allow students to decide how they are going to support the roof structure as they are printing it. Balloons can be inflated to the size they need to create domes. Cardboard can be cut to make arches or other shapes. To prevent the simulated lunar cement from permanently bonding to the temporary support structures, they can be dusted with powder or flour.
- Once the teams have completed the roofs of their lunar habitats, have them once again carefully place their models in a safe place to dry. Have teams clean their workstations.
- After the structures have dried, have the teams carefully remove any of the temporary supports they used to support the construction of the roof
- Their habitat models are now complete

## TEST

- Have the teams inspect their lunar habitat models:
  - Do they have any damage?
  - What was the source of the damage? (Cracking from drying, bad adhesion, fell under its own weight, etc.)
- Perform some structural tests on the models. Have the students record the results.
  - Light shaking to simulate a Moon quake
  - Drop a small object such as a marble or coin on the model from a height of one meter to simulate a meteor impact
  - Toss a handful of sand and/or fine gravel at the model to simulate debris kicked up from the thrust of a landing or departing rocket

## IMPROVE

- If time and supplies permit, allow students to repair any damage to their lunar habitat models

## SHARE

- Have each team present their lunar habitat to the class, explaining their design and build process. The teams should also include answers to the following questions in their presentation.
  - What challenges did you face in the design and building of your lunar habitat model?
  - How did you overcome those challenges?
  - What was one contribution that each team member made to the project?
  - What idea, design, or technique did you implement that you think was novel or creative?
  - What was something about another team's model that impressed you?

## Extensions

- Have the students try different recipes or ratios of ingredients to make several batches of different simulated lunar cement and build sample walls from each. When structures are dry, have the students come up with different tests to determine the strengths and weaknesses of each recipe.

## Resources

- "NASA Report Outlines Plan for Sustained Moon Presence": <https://appel.nasa.gov/2020/04/28/nasa-report-outlines-plan-for-sustained-moon-presence/#:~:text=In%20early%20April%2C%20NASA%20released%20a%20document%20prepared,required%20for%20the%20first%20human%20mission%20to%20Mars>
- "In-situ resource utilization": [www.nasa.gov/isru](http://www.nasa.gov/isru)
- "NASA ScienceCasts: Cementing Our Place in Space": <https://youtu.be/IsiyNZeUfUU>

# Activity Three: Print a Lunar Habitat

## STUDENT HANDOUT

### Your Challenge

Your challenge is to work as a team to design a lunar habitat for a crew of four astronauts. You will then transfer a floor plan, based on your design, onto a sheet of cardboard. Next you will use your floor plan as the template to begin making a model of your habitat with simulated lunar cement and 3D printing techniques.

Criteria	Constraints
Designs must contain necessary areas for a crew of four astronauts.	Simulated lunar cement cannot be applied by smearing or with any tool other than the frosting bag.
Design must fit on the cardboard sheet provided.	The size of the floor plan should not exceed 18x24 inches.
Must build the habitat by using 3D printing supplies provided by the teacher.	
May use inflated balloons or other items to support the roof of the structure as long as such items can be removed after the structure dries.	

### ASK

- Consider the following questions and discuss with your class as directed by your teacher:
  - How much indoor space do you require to live?
  - What about your whole family?
  - What kind of separate spaces are needed in a house?
  - If you had to downsize your living space, how could you minimize any of those separate spaces?



### IMAGINE

- Imagine that you had to live and work in a habitat on the lunar surface in a team of four. Discuss the other types of spaces you would need in your habitat.
  - Remember that you will be tasked with making a 3D printed model of a lunar habitat and that it must contain all the spaces needed for a crew of four astronauts to live and work in space
  - What would your design look like? Remember to consider the build process as part of your design. The whole structure must be 3D printed from the ground up, using the simulated lunar cement. Additional materials such as an inflated balloon or pieces of cardboard may be used to support the roofs during construction but they must be removed after the structure dries.

## Share With Students



### FUN FACT!

Did you know that NASA has held competitions among universities and industry partners to develop designs and 3D printing techniques for a lunar habitat? These types of competitions allow multiple organizations to all approach a problem from unique perspectives, increasing innovation.



3D printed model of a lunar habitat created by Pennsylvania State University as part of NASA's 3D-Printed Habitat Challenge.

Learn more: [www.nasa.gov/directorates/spacetech/centennial\\_challenges/3DPHab/index.html](http://www.nasa.gov/directorates/spacetech/centennial_challenges/3DPHab/index.html)



### CAREER CORNER



Nathan Gelino, a principal investigator with the Exploration Research and Technology programs at Kennedy, examines a Zero Launch Mass 3D printer in the Granular Mechanics and Regolith Operations Laboratory

Nathan Gelino is a principal investigator and lead of 3D printing projects at Kennedy Space Center's Swamp Works. The Swamp Works team's mission is to rapidly develop technologies needed to live and work on the surface of the Moon.

Learn more: <https://www.nasa.gov/feature/kennedy-to-partner-with-previous-nasa-challenge-winner-for-lunar-research>



## PLAN

- On sheets of paper, draw plans of what your lunar habitat will look like. The drawings must include an exterior shot to show the habitat's architectural shape as well an interior floor plan to show the layout with the purpose of each room labeled.

## CREATE

- Using your interior floor plan as a guide, transfer your floor plans onto a large sheet of cardboard provided by your teacher. The cardboard should be large enough for each room to be clearly defined when the model is complete, but not so large that it wastes materials and is too flimsy to construct.
- For the 3D printing portion of the activity, your teacher will provide
  - Your cardboard floor plan templates
  - Premade simulated lunar cement (or the ingredients to make it yourselves)
  - A few cake decorating bags
  - Scissors
  - Spoon or spatula
  - Sand and or fine gravel
  - Cardboard scraps
- First, test your simulated lunar cement; then adjust the mixture to find the right consistency that works for you
  - Spoon a small amount of simulated lunar cement into a cake decorating bag
  - Cut just a small amount off the tip of the bag to make a small hole
  - Using scrap pieces of cardboard, practice extruding the simulated lunar cement in straight and curved lines as well as trying to stack lines on top of each other to build three-dimensional shapes
  - Experiment with the consistency of your cement by adding sand and/or fine gravel to the mixture. You want the consistency to be thick enough to be stack layers on top of each other, but not too thick to squeeze from the bag. Note: Adding sand and/or fine gravel to the cement will make it stronger and thicker, similar to how adding aggregate strengthens concrete. Adding too much, though, may make it more difficult to squeeze the cement from the cake decorating bags.
  - Also experiment with the size of the hole in the tip of their cake decorating bags. A larger whole will extrude a thicker and wider layer of cement with each pass. The ideal thickness of each layer is between 0.5 and 0.75 cm (or about  $\frac{1}{4}$  to  $\frac{1}{2}$  inches) thick. Be careful not to cut too much off the tip of the bag.
- Once your team has made your adjustments to your simulated lunar cement mixtures, you can now begin building the walls of your habitat, following the floor plans you created. Try and make consistent lines around the perimeter and any interior walls, making each pass blend into the one below it, and try to stay as level as possible.
- Once your team has reached the maximum heights of your walls and before you begin to add your roof, pause and wait for your teacher's instructions
- Your teacher will now also pass out small balloons and scraps of cardboard
- Decide how your team is going to support the roof structure as you are printing it. Balloons can be inflated to the size you need to create domes. Cardboard can be cut to make arches or other shapes. To prevent the simulated lunar cement from permanently bonding to the temporary support structures, they can be dusted with powder or flour.
- Once your team has completed the roof of your lunar habitat. Carefully place the model in a safe place to dry and clean your workstations.
- After the structures have dried, carefully remove any of the temporary supports you used to support the construction of the roof
- Your habitat model is now complete

## TEST

- Inspect your lunar habitat model:
  - Does it have any damage?
  - What was the source of the damage?
- Your team will now perform some structural tests on your model. Record any damage to your model habitat.
  - Lightly shake the model to simulate a Moon quake

- Drop a small object on the model, such as a marble or coin, from a height of one meter to simulate a meteor impact
- Toss a handful of sand and/or fine gravel at the model to simulate debris kicked up from the thrust of a landing or departing rocket



## **IMPROVE**

- If time and supplies permit, repair any damage to your habitat model



## **SHARE**

- Prepare to present your lunar habitat to the class, explaining design and build process. Your team should also include answers to the following questions in their presentation:
  - What challenges did you face in the design and building of your lunar habitat model?
  - How did you overcome those challenges?
  - What was one contribution that each team member made to the project?
  - What idea, design, or technique did you implement that you think was novel or creative?
  - What was something about another team's model that impressed you?

# Activity Four: Extract, Pack, Transport

## EDUCATOR NOTES

### Learning Objectives

Students will

- Gather data by spectroscopically locating simulated ilmenite
- Collect simulated ilmenite by mining the simulated lunar surface
- Gather data while extracting oxygen from the simulated ilmenite over time
- Design and test a cold fuel transfer system

### Challenge Overview

In this activity, students will work in small groups to locate simulated ilmenite (ice with crushed effervescent tablets) and mine it. Students will work together to design a cold fuel transfer system to store the ilmenite discovered for transfer to Gateway. Future exploration missions will include visits to the Gateway, a space habitat in orbit around the Moon. NASA and its partners will use the Gateway to create a permanent presence in cislunar space that will drive activity with commercial and international partners, help explore the Moon and its resources, and leverage that experience toward human missions to Mars.

### Suggested Pacing

60 to 90 min (with educator preparation the day before and one overnight for student projects)

### National STEM Standards

Science and Engineering (NGSS)	
<p><b>Disciplinary Core Ideas</b></p> <ul style="list-style-type: none"><li>• <b>MS-PS1-2 Matter and its Interactions:</b> Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.</li><li>• <b>MS-PS1-4 Matter and Its Interactions:</b> Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.</li><li>• <b>MS-PS3-3 Energy:</b> Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.</li><li>• <b>MS-PS3-4 Energy:</b> Plan an investigation to determine the relationship among the energy transferred, type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.</li><li>• <b>MS-ETS1-1 Engineering Design:</b> Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.</li><li>• <b>MS-ETS1-3 Engineering Design:</b> 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.</li><li>• <b>MS-ETS1-4 Engineering Design:</b> Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.</li></ul> <p><b>Crosscutting Concepts</b></p> <ul style="list-style-type: none"><li>• <b>Cause and Effect:</b> may be used to predict phenomena in natural or designed systems.</li><li>• <b>Energy and Matter:</b> The transfer of energy can be tracked as energy flows through a designed or natural system.</li><li>• <b>Influence of Science, Engineering, and Technology on Society and the Natural World:</b> The uses of technologies and limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions.</li></ul>	<p><b>Science and Engineering Practices</b></p> <ul style="list-style-type: none"><li>• <b>Analyzing and Interpreting Data:</b> Analyze and interpret data to determine similarities and differences in findings.</li><li>• <b>Constructing Explanations and Designing Solutions:</b> Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process or system.</li><li>• <b>Planning and Carrying Out Investigations:</b> Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim.</li><li>• <b>Asking Questions and Defining Problems:</b> Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.</li><li>• <b>Developing and Using Models:</b> Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs.</li></ul>

## Technology (ISTE)

### Standards for Students

- 1.1.d Empowered Learner: Students understand the fundamental concepts of technology operations, demonstrate the ability to choose, use and troubleshoot current technologies and are able to transfer their knowledge to explore emerging technologies.
- 1.4.a Innovative Designer: Students know and use a deliberate design process for generating ideas, testing theories, creating innovative artifacts or solving authentic problems.
- 1.4.c Innovative Designer: Students develop, test and refine prototypes as part of a cyclical design process.

- 1.5.b Computational Thinker: 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.
- 1.7.c Global Collaborator: Students contribute constructively to project teams, assuming various roles and responsibilities to work effectively toward a common goal.

## Mathematics (CCSS)

### Mathematical Practices

- **MP.2: Reason abstractly and quantitatively.**
- 7.EE.3: Solve multi-step real-life and mathematical problems posed with positive and negative rational numbers in any form (whole numbers, fractions, and decimals), using tools strategically. Apply properties of operations to calculate with numbers in any form; convert between forms as appropriate; and assess the reasonableness of answers using mental computation and estimation strategies.

### Mathematical Practices (continued)

- 6.NS.C.5: Understand that positive and negative numbers are used together to describe quantities having opposite directions or values (e.g., temperature above/below zero).
- 6.G.A.2: 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.

## Challenge Preparation

- Read the Introduction and Background section for this guide and the Educator Notes for this activity
- Prepare a divided plate for each group the day before. For each plate
  - Crush up three effervescent tablets and mix with enough crushed ice to fill one section of the plate. Work quickly so that the ice does not melt and activate the effervescent tablets
  - Place only crushed ice into the other sections of the plate
  - Store plates in a freezer until students are ready to conduct the test procedure
- Prepare materials and set up an area in the room where students can retrieve the items they plan on using
- This activity also requires leaving the liquids overnight (and a second night if you require a redesign) to record the amount of evaporation in the storage devices the students create. This schedule can be adapted to fit your situation but be aware that it takes several hours for evaporation. If students do not have time for testing their transfer system the next day, at least have them come to record the evaporation and test the transfer system another day.
- Do not leave specimen in an extremely warm area of the classroom or there will be nothing to measure the next day and transfer!
- Make a copy of the data tables for the teams to record their data

## Materials

- Effervescent tablets
- Ice cubes, small flexible cooler packs, cold water, etc.
- White Styrofoam divided plates
- Cardstock
- Spoons
- Straws and coffee stirrers of various sizes
- Pipe cleaners
- Freezer, zipper disposable bags, quart size
- 8.5-inch X 11-inch red transparencies
- 8.5-inch X 11-inch blue transparencies
- Variety of recyclable materials for the cold storage device and transfer system, such as
  - Food storage tubs
  - Egg cartons
  - Small medicine cups
  - Film canisters
  - Plastic test tubes



- Bubble wrap
- Tin foil
- Clear wrap
- Insulated cups
- Cardboard or shoe boxes
- Clear tape
- Scissors
- Centimeter rulers
- Digital scale or balance
- Safety goggles
- Thermometer
- Graph paper
- Stopwatches

## Safety

- Remind students about the importance of classroom and lab safety
- Use disposable latex-free gloves as necessary
- Ensure students wear protective goggles when reacting effervescent tablets
- Ensure students practice classroom safety while performing this activity and avoid creating slip hazards due to spills. Any floor areas that may get wet should be protected from foot traffic.
- Ensure students practice safe cutting techniques when using scissors and carefully support the piece being cut while using care on the placement of the hand not holding the scissors
- Ensure students avoid moving around the room with scissors or other sharp objects

## Introduce the Challenge

- We learned many things about the Moon during the Apollo era flights. Much of this knowledge comes from the rock samples that the astronauts brought back with them from the Moon. These samples were one of the greatest benefits of sending humans to the lunar surface. Before their missions, the astronauts went through training to recognize different types of rocks and their significance. NASA's Vision for Space Exploration calls for a return to the Moon before going to Mars and beyond. We'll learn how to "live off the land" by making oxygen and rocket propellants from the local materials, and we'll be testing new technologies and operations. Living and working on the Moon will be a test run for living and working on Mars and beyond. In this lesson, you will locate and simulate the mining of ilmenite for its oxygen from the surface of the Moon. You will then collect the oxygen that is extracted from the ilmenite and design and build a cold storage device that can transfer the oxygen to the Gateway vehicle that will be orbiting the Moon.
- Review the problem with the students: How can I find and mine valuable resources from a simulated Moon surface?
- Optional video to help with background information: "NASA Now Minute: Cryogenics Test Laboratory" - YouTube: [www.youtube.com/watch?v=2lixONaEWW](http://www.youtube.com/watch?v=2lixONaEWW)

Criteria	Constraints
Use only the materials provided.	Cannot add more liquid to the sample collected.
Cold storage devices must allow access to liquid to measure evaporation/temperature change before and after the storage period.	Liquid should not leak out of the storage or transfer systems.
Cold storage device must be designed to hold the entire sample collected.	Device cannot be any larger than 20 cm <sup>3</sup> .

## Facilitate the Challenge

### ? ASK

- Ask your students if they have predictions relating to this activity and the “problem question” of how they could find and mine resources from the surface of the Moon. Remind students that the surface of the Moon is an extremely cold environment so the materials the astronauts will be collecting are cryogenic materials and will need to be stored in a manner to prevent evaporation of the oxygen that is mined from the regolith. Encourage students to share their hypothetical predictions with their group.
- Have the students put on their safety goggles (stress the importance of keeping eye protection on during this portion of the lesson)
- Have students observe their disposable plate Moon
- Have them draw a line down the center of the graph paper, label one side “Before Mining,” and sketch a drawing of the plate Moon
- Have them place the red transparency over half of the plate and place the blue transparency over the other half
- Have them look for ilmenite (effervescent tablets) by moving the transparencies around the plate. Ask: What color can you see the ilmenite through? What color hides the ilmenite? Explain that NASA researchers use colors to locate certain items on the surface of other celestial bodies, and that this is called “spectroscopically” locating the ilmenite.
- When the ilmenite is located, they should extract it from the section of the disposable plate it is in (take it off of the plate with the spoon) and place it into the zipper seal bag. Then have them zip the bag, making sure all the air is locked outside the bag.

### 💡 IMAGINE

- Now it is time for your students to design a cold storage system that will be able to transfer the fluid safely to a spacecraft (cup). There are two separate aspects to this challenge: the fuel tank (cold storage device), and a system to transfer the fuel to a spacecraft.
- Show students the following video to give them background on cryogenics: “NASA Now Minute: Cryogenics Test Laboratory” - <https://www.youtube.com/watch?v=2lixXONaEwW>
- Explain that NASA is working on keeping cryogenic rocket fuel chilled without adding too much weight to a spacecraft. Cryogenic propellants are fluids chilled to extremely cold temperatures and condensed to form liquids. Because these fluids must be kept at low temperatures, handling and storing can be difficult. Developing cryogenic fuel management technologies is essential to NASA’s future missions in science and exploration for in-space propulsion, landers, and in-situ resource utilization. NASA is working on developing new solutions for in-space storage and transfer of cryogenic propellants for higher performance, longer distance, and ability

## Share With Students



### Brain Booster

Did you know that NASA has a series of videos called “NASA Explorers” that introduce viewers to the diversity of NASA’s workforce and the ambitious missions they are working on, such as studying Moon rocks, creating space tools, and training astronauts to return to the lunar surface?

Learn more: [www.youtube.com/playlist?list=PL2aBZuCeDwITmlk6-R2QUhxhWkLzWcTm](https://www.youtube.com/playlist?list=PL2aBZuCeDwITmlk6-R2QUhxhWkLzWcTm)



### On Location



Image of astronaut on Moon: [www.nasa.gov/specials/artemis/](https://www.nasa.gov/specials/artemis/)

As NASA prepares to send astronauts back to the Moon under Artemis, the agency has identified 13 candidate landing regions near the lunar South Pole. Each region contains multiple potential landing sites for Artemis III, which will be the first of the Artemis missions to bring crew to the lunar surface, including the first woman to set foot on the Moon. The chosen regions are considered scientifically significant because of their proximity to the lunar South Pole, which is an area that contains permanently shadowed regions rich in resources and in terrain unexplored by humans.

Learn more: [www.nasa.gov/press-release/nasa-identifies-candidate-regions-for-landing-next-americans-on-moon/](https://www.nasa.gov/press-release/nasa-identifies-candidate-regions-for-landing-next-americans-on-moon/)

to carry heavier payloads than current propellants.

- Ask students what they know about cold and room temperature liquids and evaporation. (Examples might be warmer liquids evaporate faster than cold, and liquids exposed to more air evaporate faster.)
- Challenge students to design a cold storage device and a way to transfer the fuel from the storage device to a spacecraft. The transfer of fuel will take place during another class session. Remind students that the device cannot exceed 20 cm<sup>3</sup>.
- The spacecraft can be just a measuring cup. The main design focus is the cold fuel storage and the transfer of the liquid, not the spacecraft.
- Only provided materials may be used. Allow groups time to explore the materials.



## PLAN

- Teams will brainstorm and sketch their idea for a system that will keep their samples cold
- Remind them that their system must be large enough to hold the sample of ilmenite but cannot exceed 20 cm<sup>3</sup> in volume
- The design of the cold storage unit should also allow the team access to the sample to measure evaporation and temperature change before and after the storage period
- The transfer system that the teams design must move the sample from the storage unit to the spacecraft (measuring cup) as quickly as possible
- Be sure all students are communicating and collaborating, and that suggestions and ideas are being documented
- Assess the students' discussions and brainstorming as they are working in their small groups



## CREATE

- Teams will build their cold storage device after receiving the educator's approval of their sketch. Review the sketch for any safety issues prior to giving approval.



## TEST

- Leave the cold storage units overnight, measuring the liquid temperature before and after the storage time-period
- Measure the amount of evaporation that occurred overnight
- Teams should record their data on the student handout. The handout can also be used to formally assess the students' collaboration and understanding of the challenge.
- Transfer of the sample will also occur the next day. Teams will demonstrate the transfer of fuel from the cold storage device to the spacecraft (measuring cup).
- After teams have tested their fluid transfer system, they should record their observations and answer all the challenge questions on the student handout



## IMPROVE

- Allow teams to redesign their cold-storage system if there is time



## SHARE

- Engage students with the following discussion questions:
  - What designs were most successful in keeping the sample the coldest? Why?
  - Which designs prevented the most evaporation? Why?
  - Which designs transferred the most fuel to the spacecraft? Why?
  - What information could engineers working on this project learn from your team's results?
  - What do you think would be the best way to present your results?
- Optional: Have student groups share the tool they have invented with other classes or grade levels
- Optional: Share student results on social media using #NextGenSTEM. Be sure to include the module and activity name

## Extensions

- Include a budget for the design. Make a cost per item used and require students to stay within a certain budget or bid for contract with the lowest cost solution.
- Interview parents or grandparents about technology in their lifetime. What was the newest technology they remember as they were growing up? (e.g., color television, telephones) What did they think life would be like now? (e.g., flying cars, etc.)

## References

Moon Mining Activity - [www.nasa.gov/pdf/146862main\\_Moon\\_Mining\\_Educator.pdf](http://www.nasa.gov/pdf/146862main_Moon_Mining_Educator.pdf)

Cryogenic Propellant Storage and Transfer Activity <https://www.nasa.gov/news-release/nasa-tests-game-changing-composite-cryogenic-fuel-tank/>

First Woman Camp Experience <https://www.nasa.gov/stem-content/first-woman-graphic-novel/>

## Resource

Cryogenic Propellant Storage and Transfer (CPST) <https://www.nasa.gov/news-release/nasa-tests-game-changing-composite-cryogenic-fuel-tank/>



# Activity Four: Extract, Pack, Transport

## STUDENT HANDOUT

### Your Challenge

In this activity, you will be working in small groups to locate simulated ilmenite (ice with crushed effervescent tablets) and mine the ilmenite. You will work together to design a cold fuel transfer system to store the ilmenite that you have discovered for transfer to Gateway, a space habitat in orbit around the moon.

Criteria	Constraints
Use only the materials provided.	Cannot add more liquid to the sample collected
Cold storage devices must allow access to the liquid to measure evaporation and temperature change before and after the storage period.	Liquid should not leak out of the storage or transfer systems.
Cold storage device must be designed to hold the entire sample collected.	Device cannot be any larger than 20 cm <sup>3</sup> .

### ?ASK

- Put on your safety goggles and observe your disposable plate Moon with your team
- Draw a line down the center of the graph paper, label one side "Before Mining," and sketch a drawing of your plate Moon
- Place the red transparency over half of the plate and place the blue transparency over the other half
- Look for ilmenite (effervescent tablets) by moving the transparencies around the plate. What color can you see the ilmenite through? What color hid the ilmenite? NASA researchers use colors to locate certain items on the surface of other bodies. This is called "spectroscopically" locating the ilmenite.
- When the ilmenite is located, extract it from the section of the disposable plate it is in (take it off of the plate with the spoon) and place it into the zipper seal bag. Zip the bag, making sure all the air is locked outside the bag

### 💡IMAGINE

Now it is time to design a cold storage system that will be able to transfer the fluid safely to a spacecraft (cup). There are two separate aspects to this challenge: the fuel tank (cold storage device), and a system to transfer the fuel to a spacecraft.

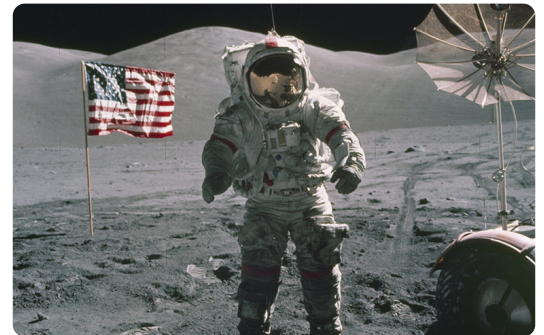
- NASA is working on keeping cryogenic rocket fuel chilled without adding too much weight to a spacecraft. Cryogenic propellants are fluids chilled to extremely cold temperatures and condensed to form liquids. Because these fluids must be kept at low temperatures, handling and storing can be difficult. Developing cryogenic fuel management technologies is essential

## Share With Students



### FUN FACT!

American astronauts have planted six American flags on the Moon. But that doesn't mean the United States has claimed it; in fact, an international law written in 1967 prevents any single nation from owning planets, stars, or any other natural objects in space.



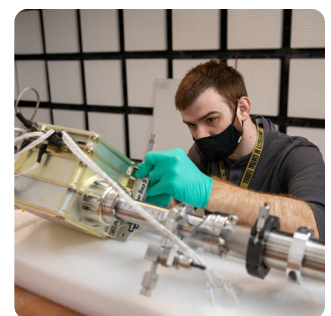
This is an Apollo 17 Astronaut standing upon the lunar surface with the United States flag in the background.

Learn more: [https://solarsystem.nasa.gov/Moons/earths-Moon/overview/#otp\\_pop\\_culture](https://solarsystem.nasa.gov/Moons/earths-Moon/overview/#otp_pop_culture)



### CAREER CORNER

Nate Cain, an electronics engineer at NASA's Kennedy Space Center in Florida, prepares to conduct



Nate Cain, Credit: NASA

electromagnetic interference (EMI) testing for the Mass Spectrometer Observing Lunar Operations (MSolo) instrument. On the Moon, it will help analyze the chemical makeup of landing sites, with later missions studying water on the lunar surface..

Learn more: [www.nasa.gov/image-feature/engineer-tests-msolo-instrument-for-viper](http://www.nasa.gov/image-feature/engineer-tests-msolo-instrument-for-viper)

to NASA's future missions in science and exploration for in-space propulsion, landers, and in-situ resource utilization. NASA is working on developing new solutions for in-space storage and transfer of cryogenic propellants for higher performance, longer distance, and ability to carry heavier payloads than current propellants. It is now your challenge to design a cold storage device and a way to transfer the fuel from the storage device to a spacecraft.

- The spacecraft can be just a measuring cup. The main design focus is the cold fuel storage and the transfer of the liquid, not the spacecraft
- Only provided materials may be used, so take a look at the materials your teacher has provided

## **PLAN**

- Brainstorm and sketch your team's idea for a system that will keep your samples cold
- Remember that your system must be large enough to hold the sample of ilmenite
- The design of the cold storage unit should also allow your team access to the sample to measure evaporation and temperature change before and after the storage period
- The transfer system design must move the sample from the storage unit to the spacecraft (measuring cup) as quickly as possible
- Be sure all suggestions and ideas from your team members are being documented

## **CREATE**

- Your teams will build the cold storage device after receiving your educator's approval of your sketch

## **TEST**

- Leave the cold storage units overnight, measuring the liquid temperature before and after the storage time-period
- Measure the amount of evaporation that occurred overnight
- Record your data on the student handout
- Transfer of the sample will also occur the next day. Your team will demonstrate the transfer of fuel from the cold storage device to the spacecraft (measuring cup).
- After you have tested your team's fluid transfer system, record your observations and answer all the challenge questions

## **IMPROVE**

- Redesign their cold-storage system if there is time

## **SHARE**

Read and discuss the following questions with your team and be prepared to share with the other teams:

- What designs were most successful in keeping the sample the coldest? Why?
- Which designs prevented the most evaporation? Why?
- Which designs transferred the most fuel to the spacecraft? Why?
- What information could engineers working on this project learn from your team's results?
- What do you think would be the best way to present your results?

# Experiment and Record

## Design 1

Measurements of your storage system: L(cm)\_\_\_ W(cm)\_\_\_ H(cm)\_\_\_ Total volume: (cm<sup>3</sup>)\_\_\_

### Cold Storage

1. Before storage period record:

Mass of an entire storage device without liquid (in grams)	Amount of liquid in cold fuel storage (in cm <sup>3</sup> )	Mass of entire device with liquid (in grams)	Temperature of liquid at start of test (in degrees Celsius)

2. Storage time: \_\_\_\_\_

3. After storage period record:

Temperature (in degrees)	Mass of entire device (in grams)	Difference in mass due to evaporation (in grams)

### Transfer System

1. Mass of transfer system: (grams) \_\_\_\_\_

2. Results of transfer spacecraft.

Amount of liquid at start of transfer (in cm <sup>3</sup> )	Amount of liquid at end of transfer in spacecraft (in cm <sup>3</sup> )

(The spacecraft can be a measuring device to make it easier to see how much was transferred.)

# Experiment and Record

## Redesign

Measurements of your storage system: L(cm)\_\_\_ W(cm)\_\_\_ H(cm)\_\_\_ Total volume: (cm<sup>3</sup>)\_\_\_

### Cold Storage

1. Before storage period record:

Mass of an entire storage device without liquid (in grams)	Amount of liquid in cold fuel storage (in cm <sup>3</sup> )	Mass of entire device with liquid (in grams)	Temperature of liquid at start of test (in degrees Celsius)

2. Storage time: \_\_\_\_\_

3. After storage period record:

Temperature (in degrees Celsius)	Mass of entire device (in grams)	Difference in mass due to evaporation (in grams)

### Transfer System

1. Mass of transfer system: (grams) \_\_\_\_\_

2. Results of transfer spacecraft.

Amount of liquid at start of transfer (in cm <sup>3</sup> )	Amount of liquid at end of transfer in spacecraft (in cm <sup>3</sup> )

(The spacecraft can be a measuring device to make it easier to see how much was transferred.)



# Quality Assurance

Each team is to review another team's design, then answer the following questions








Team Name:	Yes	No	Notes
Was the team able to store 30 mL of liquid overnight?			
Was the team able to transfer all 30 mL of liquid?			
Did the team correctly record data?			

**List specific strengths of the design**

**List specific weaknesses of the design**

**How would you improve the design?**

## Appendix A. – Rubric for Engineering Design Process (EDP)

EDP Step	Novice (0)	Apprentice (1)	Journey person (2)	Expert (3)	Level of student knowledge (Score)
<b>Identify the problem (ASK)</b> 	Student/Team does not identify the problem	Student/Team incorrectly identifies the problem	Student/Team identifies part of the problem	Student/Team fully and correctly identifies the problem	
<b>Brainstorm a solution (IMAGINE)</b> 	Student/Team does not identify knowns and unknowns	Student/Team incompletely identifies knowns and unknowns	Student/Team identifies knowns and unknowns using experience but uses no resources	Student/Team completely identifies knowns and unknowns using experience and resources	
<b>Develop a solution (PLAN)</b> 	Student/Team does not brainstorm	Student/Team generates one possible solution	Student/Team provides two possible solutions	Student/Team provides three or more possible solutions	
<b>Create a prototype (CREATE)</b> 	Student/Team does not identify any consequences	Student/Team determines inaccurate or irrelevant consequences	Student/Team identifies consequences accurately	Student/Team identifies consequences accurately and provides a rationale	
<b>Test a prototype (TEST)</b> 	Student/Team does not communicate results	Student/Team shares random results	Student/Team shares organized results, but results are incomplete	Student/Team shares detailed, organized results with class	
<b>Redesign based on data and testing (IMPROVE)</b> 	Student/Team does not contribute to the redesign	Student/Team does not improve the design or address concerns	Student/Team addresses one concern to improve the design	Student/Team addresses two or more test-based concerns to improve the design	
<b>Communicate results from testing (SHARE)</b> 	Student/Team does not communicate results	Student/Team shares random results	Student/Team shares organized results, but results are incomplete	Student/Team shares detailed, organized results with the group	
<b>Total</b>					

Note to educator: You may customize the above rubric to better assess your group of students.

## Appendix B. – Glossary of Key Terms

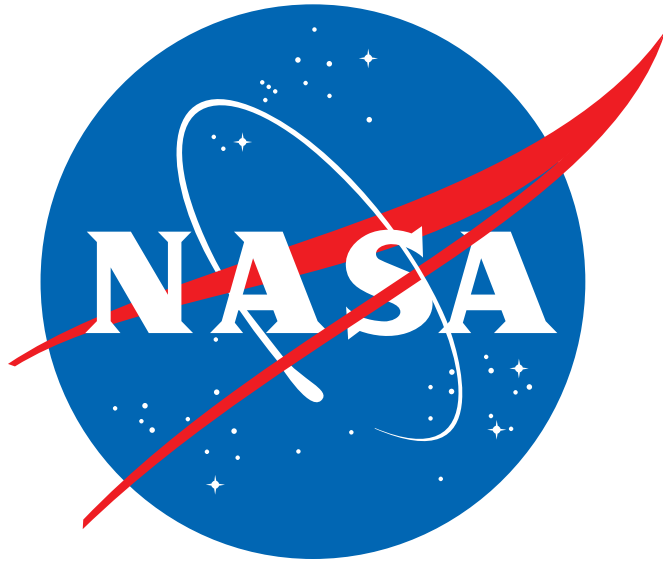
**Icy-regolith** - Ice and regolith mixture found on the Moon.

**Ilmenite** - A mineral composed of iron and titanium oxide. A major resource for oxygen on the Moon.

**In-situ resource utilization (ISRU)** - A practice of generating products with local materials.

**Lunar dust** - A very fine layer of regolith, or fragmented rock material, that is static and adheres to exposed surfaces.

**Regolith** - The loose, fragmental material on the Moon's surface.



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