National Aeronautics and Space Administration

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

Education Product	
Educators and Students	Grades 5-8

Contents

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	• The students are introduced to the challenge using a video • Allow opportunity to activate prior knowledge and offer complementary sources such as a video
Teamwork section (pg.3)	Power and Participation	• Consider assigning teams team roles. An example is found in the Teamwork section of the guide
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	• Give students a copy of the glossary or make it accessible to all students • Have students share information or examples in groups • Have students present their final designs to other groups in the class
Engineering Design Process Rubric pg. 43 Ask section for each activity (pg.11,19,26,35)	High Expectations	• There is a rubric provided that may be used for grading • Student inquiry and critical thinking can be promoted by asking students to make predictions, which can then be tested • Cooperative learning that promotes problem solving
Plan and Create sections for each activity (pg.12,20,26,36)	Student Identity and Funds of Knowledge	• 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.
Share sections for each activity (pg.13,21,28,36)	Critical Knowledge and Social Justice	• Make connection to personal/community/cultural knowledge and role models from the community • 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.

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/.

? **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.

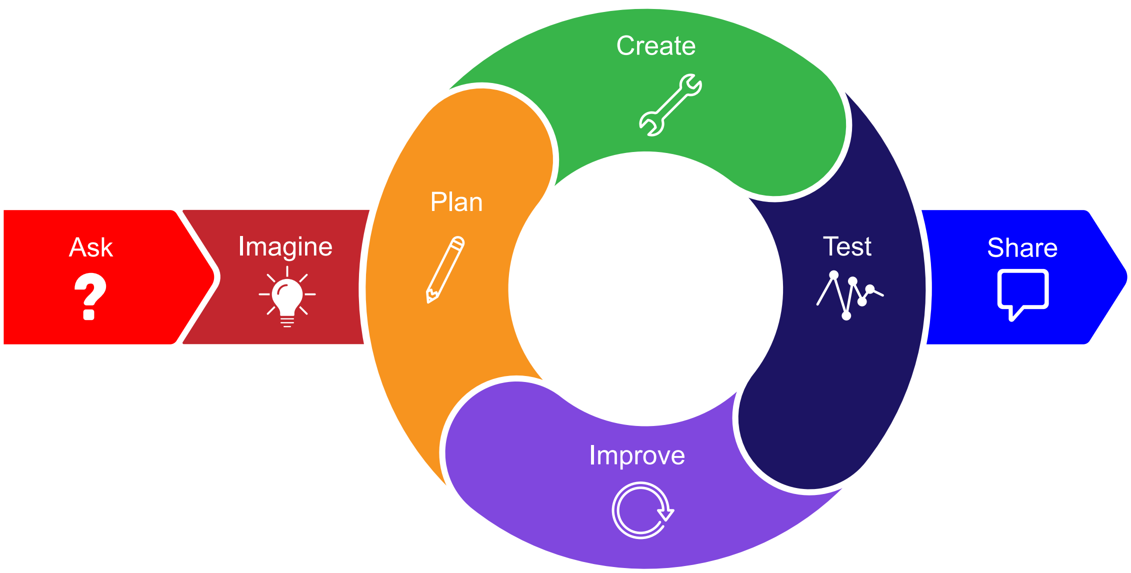
PLAN: Select and sketch a design.

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

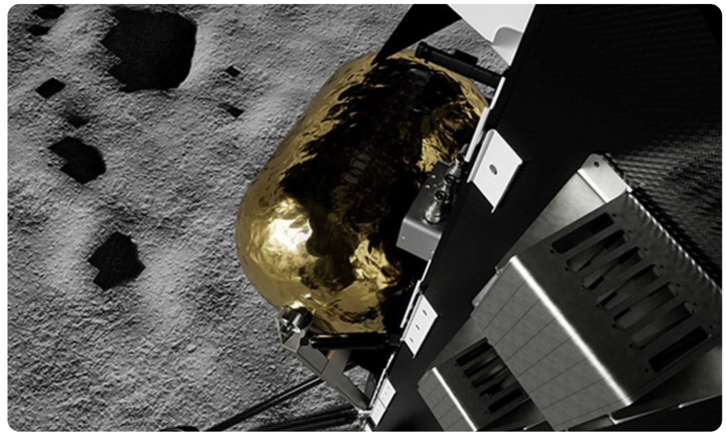
Moon dust isn't like the stuff that collects on a bookshelf or on tables – it's ubiquitous and abrasive, and it clings to everything. It's so bad that it even broke the vacuum NASA designed to clean the Moon dust off Apollo spacesuits. With NASA's return to the Moon and its orbit, we will need to manage 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 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

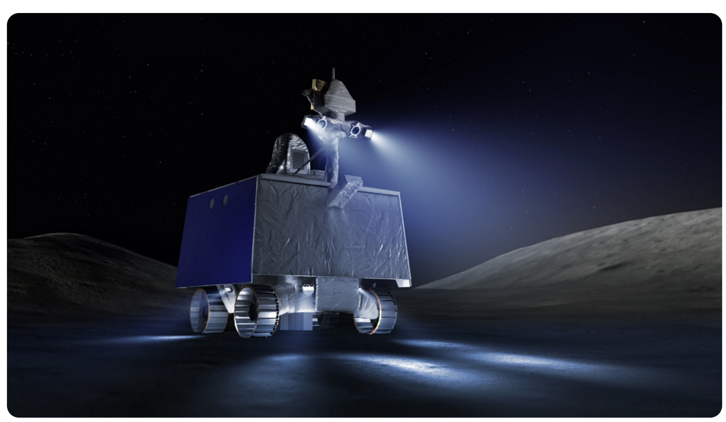
Drilling on the Moon

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

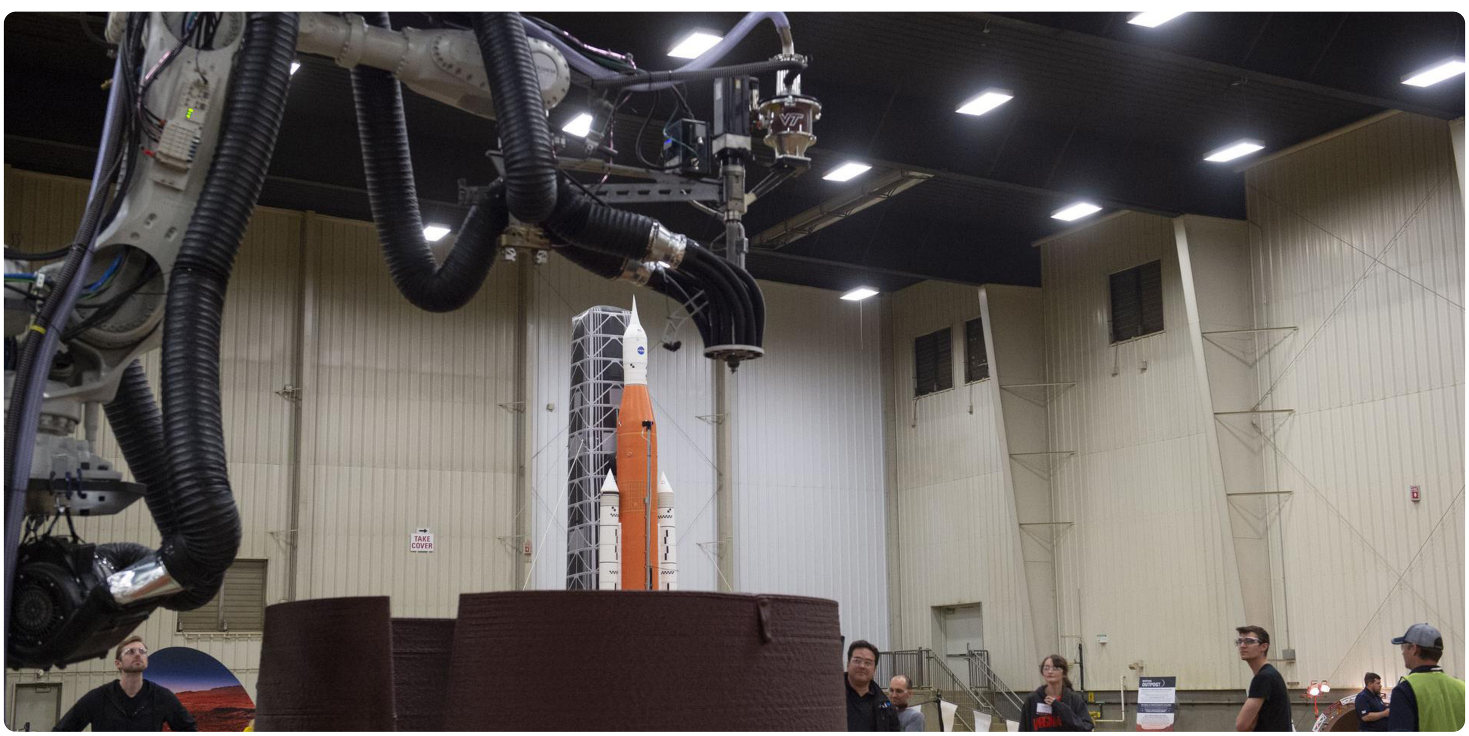
After the PRIME-1 mission, the Volatiles Investigating Polar Exploration Rover (VIPER)will explore the relatively nearby but extreme environment of the Moon in search of ice and other potential resources. VIPER will directly look for water as a usable resource on the surface and subsurface of the Moon 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.

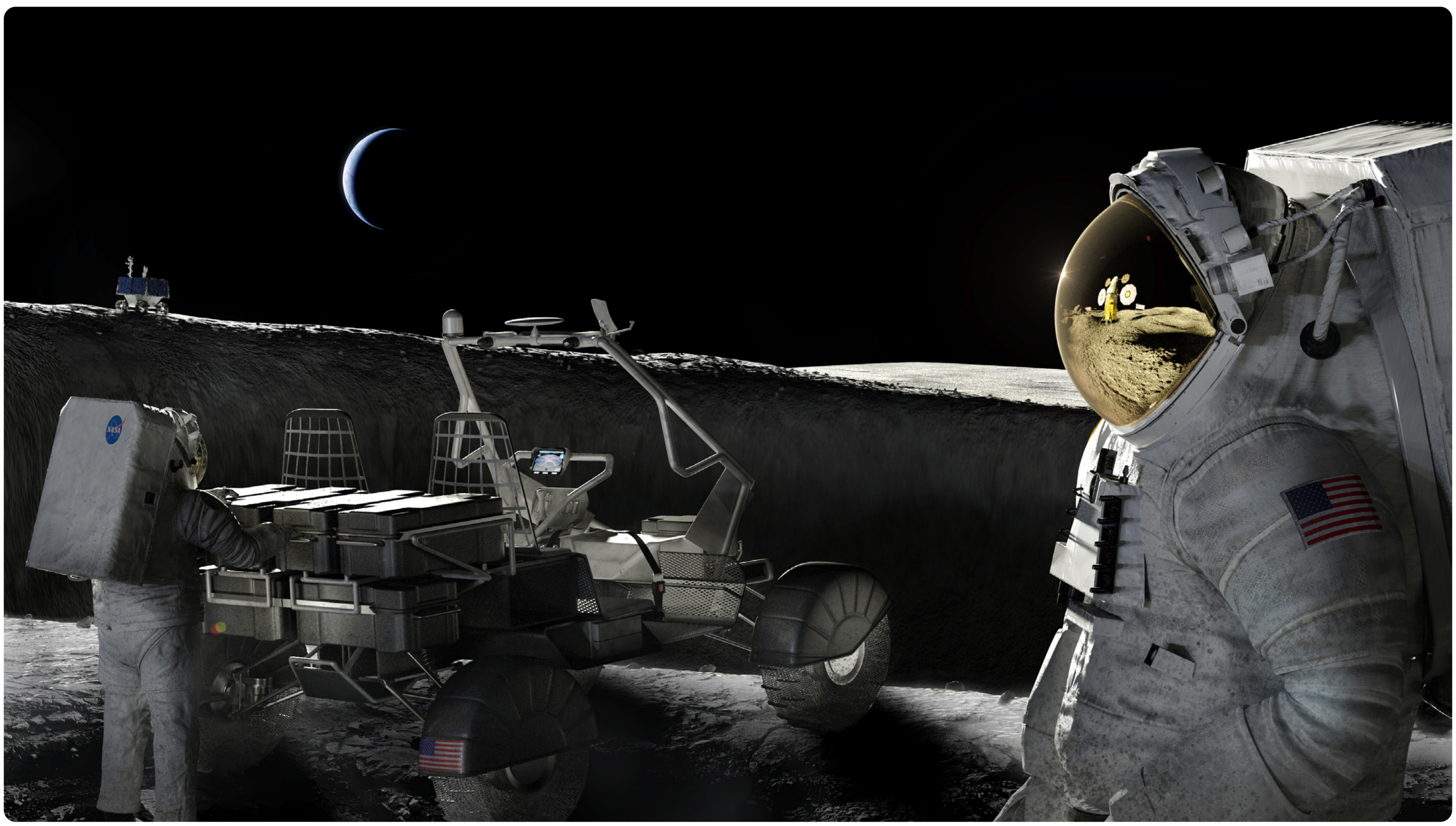
It would be virtually impossible to transport from Earth the resources needed to build this infrastructure. Instead, NASA and its partners have been developing ways to use lunar regolith as a basis for creating concrete-like material on the Moon. Turning this lunar concrete into structures will be accomplished 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