Why Go To The Moon?

There are almost as many answers to this question as there are craters on the Moon — depending on your interests! The Moon formed from Earth, and holds a record of Earth's early history — a record that has been erased on Earth by restless geologic processes. The Moon will provide scientists with new views of early Earth, how the Earth-Moon system and the solar system formed and evolved, and the role of asteroid impacts in influencing Earth's history — and possibly future!

The Moon presents numerous exciting engineering challenges. It is an excellent place to test technologies, flight capabilities, life support systems, and exploration techniques to reduce the risks and increase the productivity of future missions. Our journey will provide us with the first experience of living and working on another world, allowing us to test advanced materials and equipment in the temperature and radiation extremes of space. We will learn how to best employ robots to support human tasks, explore remote locations, and gather information in potentially hazardous regions. By successfully establishing a presence on the Moon, we will enhance life on Earth and prepare to explore the rest of our solar system — and beyond!

Keeping astronauts healthy in a lower-gravity and higher-radiation environment than Earth is an important challenge for medical researchers. The potential benefits to all humans are tremendous in terms of prevention and treatment of bone and muscle loss and some cancers. Other advances in medicine will follow! Exploration of the Moon also creates new business opportunities for technological innovations and applications and utilization of new resources. Finally, establishing outposts on the Moon enables adventurers and explorers to extend exploration and settlement to planets and moons beyond Earth. There is an entire universe of unknowns waiting for us to investigate!

Why do YOU think we should journey to the Moon and beyond?

Exploration of the Moon is a global undertaking. It offers a shared challenge that requires investment by many nations. Success in our journey to the Moon and beyond requires the preparation and involvement of planetary scientists, engineers, medical researchers, physicists, chemists, mathematicians, mechanics, materials scientists, architects, doctors, communications and safety specialists, computer programmers, and many others.

BE PART OF THE JOURNEY!

Meet A Mission Engineer — Ms. Cathy Peddie, NASA Goddard Space Flight Center

What do you do? Right now I am the Deputy Project Manager for the Lunar Reconnaissance Orbiter (LRO) Mission. That means that I oversee the entire project. I make sure that we meet our technical goals when we are designing the instruments and the spacecraft, that we meet our budget goals, and that the people on the project — the scientists and engineers and technicians and support people — have everything they need, when they need it, to do their jobs. I did not start as a Deputy Project Manager. I began working at NASA over 20 years ago as an engineer on a project. I grew into my position today by experiencing different projects and getting training all along the way.

The best things about my job are that I am always learning, I get to work on exciting and challenging projects, and I get to work with really cool people. I mean, how exciting is it to design a spacecraft to go to the Moon? And to only have 3 or 4 years to do it?!

How did you get to be doing what you are doing? When I was a little girl in Hawaii, I wanted to work in space. I liked math and was encouraged to be a math teacher. One of my math teachers suggested that I go into the Air Force because they offered scholarships that would pay for my schooling, and a guaranteed job. The Air Force also offered real experiences using what I learned — and they worked in space. One of my jobs was working on satellites. When I left the military, the experience helped me to get a job at NASA. My first job was figuring out how to put satellites into the space shuttle and then, once the shuttle was in space, get the satellites out and into orbit. All through my career I have had to use math and engineering. All those boring classes that I had to take when I would have preferred to be surfing really paid off! I am always using what I learned in school!

What is the greatest engineering challenge about putting an outpost on the Moon? The most challenging — and most interesting — part of putting an outpost on the Moon is that there is still so much we don't know about our Moon! The Moon is so close. We have astronomers studying it, and we have visited it, and yet we know so little. This is a huge challenge to designing an outpost. We need to know what the land is like and what materials and resources are there. We are pioneers again. Missions like LRO and the Lunar Crater Observation and Sensing Satellite (LCROSS) mission and others will help us learn so much more, building on what we know from the Apollo missions 40 years ago.

Engineers will work with the scientists to figure out what resources are where on the Moon. We'll know if there is water, and what metals and other resources might be available to build an outpost. Once we have picked the best site for an outpost, the engineers will determine how to use the resources available, what equipment is needed to gather and make use of the resources, and what we still need to bring from Earth. They will design and build roads, bridges, transportation, and buildings that are suited for the location.

Why should we return to the Moon? At least for me, the Moon is our natural next step to exploring our universe — and there is so much to explore! When people ask "Why do it?" I want to say "Why not?" But there are also benefits to be discovered. Our society has benefited so much from the space program — the materials that make my glasses lightweight and flexible, the products in my house like cordless tools and computers — all resulted from the space program. Who knows what will be discovered as we venture to the Moon?

If someone wants to be an engineer, what should they do? It is really important that students consider going into science and engineering careers. We need people who are good at these jobs for our future exploration of the Moon and Mars and other places in our solar system. I love a challenge and I love problem solving. If a student likes to solve puzzles, have fun, work with neat people on challenging problems that require imagination, then science and engineering are for them! They should focus on science and math and listen to their teachers. I met many great teachers who wanted to help me learn and succeed. Believe it or not — and they may not! — they will use much of what they learn. I have!

Hear about the LRO Mission from Cathy at **http://learners.gsfc.nasa.gov/mediaviewer/LRO/**.

HALLENGES T LUNAR EXPLO ERS

The Moon is very different from Earth! Understanding the lunar environment and its hazards, combined with innovative engineering and technology, will prepare the way for future astronauts to live and work there.

Imagine working on the nearside of the Moon — the side facing Earth. Due to the lack of atmosphere, the sky is black, even during the day when the Sun shines. The distant Earth in the sky appears smaller than a quarter held at arm's length. The Moon's day is 29.5 Earth-days long. On much of the Moon's surface daylight lasts a little over 14 Earth days, followed by 14 days of darkness. The long-term impact of living in remote, small communities with prolonged light and darkness is unknown, so NASA is learning more by studying people living in remote communities near Earth's poles.

The Moon's poles have areas of permanent light and permanent darkness. Because the Moon's axis of spin is tilted at a very small 1.5 degrees to its orbit around the Sun, sunlight reaches the north and south polar regions at low angles of incidence. Explorers at the Moon's poles will see a Sun that stays near the horizon. Deep craters at the poles never receive sunlight. They are permanently shadowed and permanently cold! In contrast, elevated polar regions, such as crater rims, receive light for extended periods, making them valuable locations for solar energy to power polar bases.

Without an atmosphere to temper the differences, the lunar surface is either very hot or very cold. Average temperatures range from 225°F (107°C) in sunlight to –243°F (–153°C) in the dark. Astronauts will need protection from these extremes through suits and shelters. Equipment will also need to be sheltered and shaded as it operates best at a consistent, typically cold, temperature.

The Moon's gravity is approximately one-sixth of Earth's, so objects weigh one-sixth of their Earth weight. Building materials and structures will bear less weight than on Earth. While lunar Olympians will leap higher and throw farther, the reduced gravity can have a negative effect on human bodies. Well-designed for Earth, our sturdy bones and strong muscles are not necessary in the lower lunar gravity, and they begin to deteriorate, putting astronauts at risk for broken bones and weak muscles when they are back on Earth.

On Earth, our magnetosphere and atmosphere protect us from much of the dangerous incoming solar and cosmic radiation — very-high-energy radiation that can cause damage to living tissue and DNA. The Moon has no magnetosphere or atmosphere. Travelers must provide their own protection from dangerous space radiation. Solar flares can be detected and warnings sent to outposts to ensure astronauts are protected during these events. NASA's medical researchers and engineers are investigating the effects of radiation on the human body and different types of protective materials for suits, stations, and spacecraft.

The Moon is a very dry place! No liquid water exists on its surface, so water will have to be transported or produced on location on the Moon. However, this valuable commodity may exist — in frozen form — in permanently shadowed craters near the lunar poles.

Billions of years of asteroid and comet impacts — still ongoing — have pulverized the surface of the Moon, leaving behind a layer of "soil" — regolith — that can reach up to 50 feet (15 meters) in thickness. About half of the regolith is made of dust-sized particles. Lunar "dust" poses a significant challenge as it can become engrained in delicate equipment such as astronaut life-support systems, computers, and rover instruments. NASA currently is working to understand the properties of lunar dust, the effects of long-term exposure on humans, and ways to minimize its effects.

In facing these challenges on the Moon, we will learn how to live off the land, advancing our use of available resources, as we start the next chapter in human exploration of the solar system. The Moon is our testing ground for engineering approaches and new technologies, allowing us to build and sustain living and working environments beyond Earth.

RY THIS — Ice at the Poles!

Students explore why the lunar poles may contain concentrations of ice.

Getting Started

The students should have an understanding of what causes day and night. While focused on examining why deep polar craters on the Moon are in permanent shadow, the activity can be used to explore causes of day and night and seasons on Earth and other planetary bodies.

What to Do

- Provide the students with the clay balls, toothpicks, and lamps. The clay ball represents the Moon and the lamp represents the Sun. Have the groups insert one toothpick halfway into the north pole and one toothpick halfway into the south pole of their clay Moon so that the toothpicks are perpendicular to the surface.
- Invite the students to experiment with creating day and night on the lunar surface using the lamp and ball. Explain that the Moon spins more slowly on its axis than Earth. The lunar day and the lunar night each are about the length of 14 Earth days. Because the Moon has no atmosphere to moderate surface temperatures, the Moon's surface that is in sunlight is very hot (average of 225°F/107°C), and the surface that is in darkness is very cold (average of –243°F/–153°C).

  Explain to the students that the Moon's axis is tilted only 1.5 degrees; this is much smaller than Earth's axial tilt of 23.5 degrees. Ask the students where the Sun's light most directly strikes the Moon's surface.
- Invite the students to add the rest of their toothpicks in a line stretching from the north to the south lunar pole. The toothpicks should be placed equal distances apart, perpendicular to the surface with one at the equator of their clay Moon. Have the students illuminate their Moon from two to three feet away so that the center of the beam of light is aimed at the Moon's equator.

  What do the students observe about the shadows cast by the toothpicks? The toothpick at the equator has no shadow. The toothpicks increasingly distant from the equator have increasingly longer shadows. The Sun's light — and energy — is striking most directly at the equator.

  Are there any areas on the lunar surface that are shielded permanently from the Sun? No. Even at the low levels of incident sunlight, the polar regions receive some light as the Moon rotates.

  Invite the students to examine images of the cratered lunar surface. Have them crater their clay moons by poking holes in the surface, including several half-inch-deep craters in the polar regions (the depth of cratering is greatly exaggerated in this model compared to actual crater depths on the Moon). When they illuminate their clay Moon as they did earlier, what do they observe about the light in the cratered regions? Craters across much of the surface are illuminated by the light, but the bottoms of craters at the poles stay dark all the time.

Wrapping Up

What do the student's observations suggest about temperatures in these permanently shaded craters? Because the bottoms of these craters are permanently dark, the temperatures are below freezing all the time. Comets are made, in part, of water ice; if comets delivered ice to the Moon, where might temperatures be permanently cold to preserve the ice? The craters of the polar regions that are in permanent shadow are cold enough to preserve the ice.

UNAR SO RCES

When the astronauts are living and working on the Moon, they will not be able to visit a local hardware or grocery story to get nails and lumber or peanut butter and milk. Everything they need must be shipped from Earth — at a cost of $10,000 per pound — or extracted from the materials available on the Moon. "Everything" includes propellant, power sources, construction materials, food, water, and even air.

The Moon has materials that can support a colony, and these will need to be used efficiently to make human habitation of the Moon sustainable. Once the locations and quantities of potential resources are assessed, the materials will need to be gathered and processed, and manufacturing will be necessary to transform them into usable products.

Water Ice, Maybe. Hydrogen, Yes!
Because the Moon is tilted only slightly on its axis, deep craters at the lunar poles stay in permanent shadow. These are the cold-storage pits of the lunar surface. They are cold enough to trap volatiles — elements that evaporate readily at standard temperature and pressure. Comets striking the surface of the Moon may have delivered water ice that became trapped in the permanently shadowed craters.

Radar data collected by the Clementine spacecraft suggest that water ice, perhaps mixed with regolith, exists at the lunar south pole. Spectrometers onboard the Lunar Prospector detected hydrogen — one component of water — at the lunar poles. Based on the presence and distribution of the hydrogen, scientists hypothesize the presence of extensive water ice at the poles.

Several spacecraft will provide more definitive data about the presence of water ice. NASA's Lunar Reconnaissance Orbiter (LRO) and India's Chandrayaan-1 spacecraft carry radar instruments to map the extent and distribution of materials at the poles in far greater detail than previous missions. The Lunar Crater Observation and Sensing Satellite (LCROSS) mission will help confirm the presence of water ice by impacting the lunar surface in a permanently shadowed crater. The resulting plume will be analyzed for water ice and vapor and other materials. If there is ice at the lunar poles, there are still many questions about how it got there, its composition, how fast it accumulates, and how much regolith is mixed with it.

The presence of water will reduce the cost of transporting this critical resource to the Moon. Beyond the need for drinking water, it can be separated into its two components — hydrogen and oxygen — and used to make propellant for spaceflight. The oxygen can also be used for the production of breathable air. If, however, the hydrogen in the polar regions is not contained in water ice, but accumulated from particles emplaced by solar wind, it is still a vital source of potential energy — although only part of the propellant equation!

Regolith Revisited
Oxygen, critical to future lunar outposts for fuel and breathable air, makes up about 45% of the lunar regolith. It can be extracted from regolith and rock minerals such as ilmenite through a variety of processes that break the chemical bonds. Breaking down ilmenite also produces titanium, a lightweight metal that is as strong as steel and that can withstand extreme temperature fluctuations, making it ideal for lunar structures.

Regolith also has valuable sheltering properties. It can be used to cover lunar structures, helping to regulate temperatures inside and offering protection from incoming cosmic and solar radiation. When regolith is heated, its tiny particles fuse together; future outposts may use fused regolith to create roads or make bricks for buildings.

Lunar Resources continued on next panel

Got Sun?
Energy can be collected by arrays of solar panels and stored during the lunar day, typically 14 Earth days long, and used during the lunar night to provide electricity for the outpost, life support systems, rovers, and other equipment. Sunlight is less direct at the poles, but available for more than 70% of the time on raised surfaces. Future lunar missions, like LRO, will confirm the duration of light. Solar panels placed on crater rims would capture solar energy. The key is figuring out how to store this energy. One possibility is rechargeable batteries. Another is regenerative fuel cells, "batteries" that generate power by combining hydrogen and oxygen. In regenerative fuel cells, all the materials are contained within the cell — there is no need to add resources. During the lunar day, solar power would be used to support the outpost and to split water into oxygen and hydrogen in the fuel cell. At night, the hydrogen and oxygen would be recombined in the fuel cell to generate electricity.

Other Energy Sources
Incoming solar particles, including hydrogen, helium, and small amounts of other elements, have gradually built up in the lunar regolith over billions of years. One of these, helium-3, is of particular interest because it undergoes fusion reactions, and thus has potential as an energy source for the Moon (and possibly for Earth). While the concentrations of helium-3 are low, only small amounts are needed. Some estimates suggest that mining an area on the Moon a little smaller than the city of New Orleans (about 170 square miles or 440 square kilometers) to a depth of 10 feet (3 meters) would meet the energy needs of the United States for one year. At this point in time, converting helium-3 to a viable energy source requires further advances in technology.

What's for Dinner?
With time, lunar explorers will grow their own vegetables. The lack of an atmosphere and the nutrient-poor regolith present challenges. However, scientists are designing enclosures where plants are cultivated hydroponically — in liquid nutrient solutions. Carbon dioxide, a product of human respiration, can be captured and provided to the plant enclosures. The oxygen that the plants release will help create breathable air for the astronauts.

Reduce, Reuse, Recycle
Fundamental to building and sustaining an outpost on the Moon is ensuring that all resources are used efficiently! Transporting materials to the Moon is costly and minimizing waste is essential. Habitat modules, transportation vehicles, and other equipment will be designed so that parts can be interchanged, reducing the need for a large inventory of different parts. Water in the breath exhaled by astronauts, and even from urine, will be collected, sanitized, and reused to support the outpost. New technologies, such as regenerative fuel cells and advanced solar panels, will minimize the consumption of resources and creation of waste byproducts.

Picture It
Robotic missions transport solar panels, small habitats, fuel cells, and other equipment to the Moon. Advanced robots assemble the components, initiate energy collection, and begin surface operations including excavation of lunar materials for water. Humans follow and complete the basic outpost design, ensuring safe living and working modules. Food, water, and air initially are brought from Earth; eventually, these are produced on the Moon, in part from lunar resources. Engineers, mechanics, technicians, and others maintain the outpost, ensuring that life support systems and other equipment function properly. The habitat grows as more activities get underway, including refining raw materials and manufacturing buildings and equipment components. Humans and robots work together in near- and far-ranging expeditions to establish remote instrument stations and to collect data and samples for scientific and resource analysis. Eventually, more people with different skills support the outpost operations, including base managers, medical and laboratory technicians, cooks, and others. What will your role be?

Outposts are built partially underground to protect astronauts from space radiation.

RE TE A LUNAR POST

Artist Pat Rawlings illustrates space exploration, from futuristic space travel to human investigation of Mars to lunar outposts. His images integrate imagination with scientifically and technically accurate information.

Invite your students to use materials at hand to create, draw, or animate a lunar outpost of the future. Have them consider the questions that follow as they construct their Moon habitats.

What buildings are needed for the astronauts? How does the habitat get power? What science occurs at the outpost?

How do the astronauts arrive at the outpost? How do they move across the lunar surface?

How are the astronauts protected from radiation and temperature extremes?

Where is equipment maintained and stored?

How is air generated for the astronauts to breathe?

Where do they get their food?

Where do the astronauts get medical treatment?

How do they communicate with each other and Earth?

What do the astronauts do for exercise, relaxation, and fun?

What kind of jobs will people need to do at the outpost?

Invite your students to submit their work to the Lunar and Planetary Institute at http://www.lpi.usra.edu/education/moon_poster.shtml

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Additional Reading

Home on the Moon: Living on a Space Frontier. Marianne Dyson, 2003, National Geographic Society, ISBN: 0792271939. Readers ages 10–13 will enjoy learning about the lunar environment and challenges to outposts as they imagine future exploration of our near neighbor in this well-illustrated book. Each chapter includes hands-on activities for further investigation.

Return to the Moon. David Jefferis and Mat Irvine, 2007, Crabtree Publishing Company, ISBN: 0778731170. Loaded with pictures and illustrations, this book provides readers ages 10–13 with a history of our exploration of the Moon, and a sense of the challenges and excitement of living and working at outposts in the future.

About This Poster

This is one of a three-poster set that examines how our geologic understanding of the Moon will be used as we plan to live and work there in the future. The poster **front**, designed for **sixth- to ninth-grade students**, presents the resources available for future lunar outposts. Much of our understanding of these resources is based on data from orbiting spectrometers and other instruments, and validated by Apollo samples. The poster **back** is designed to provide **educators** with background information, ideas for lessons, and resources to support further student exploration. The complete set of posters can be found at **http://www.lpi.usra.edu/education/moon_poster.shtml**.

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