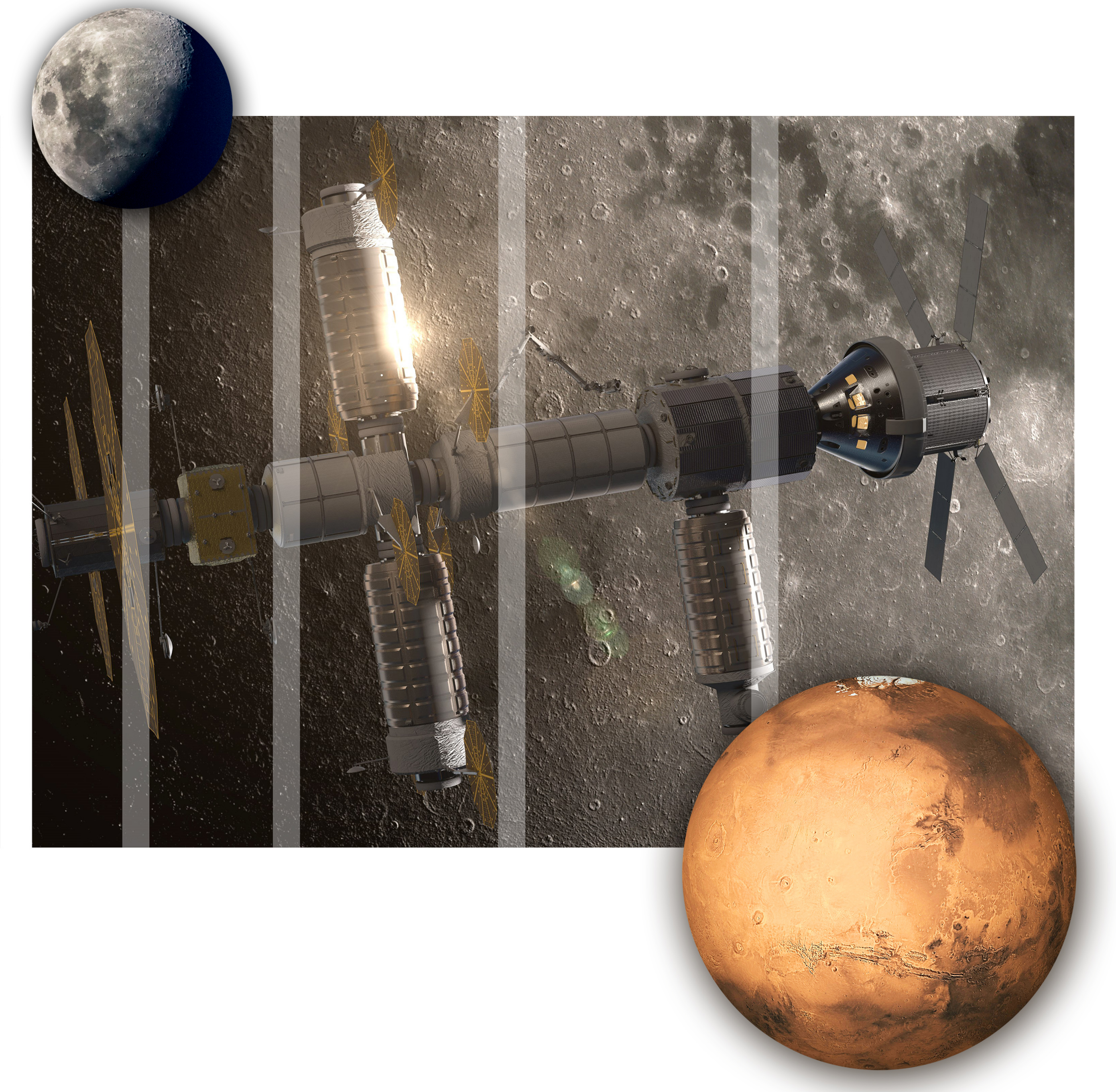
National Aeronautics and
Space Administration

Habitation With Gateway

Educator Guide



Educator Guide	
Educators and Students	Grades 6 to 8

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Preface

Habitation With Gateway was published by NASA's Office of STEM Engagement as part of a series of educator guides to help middle school students reach their potential to join the next-generation STEM workforce. The activities can be used in both formal and informal education settings as well as by families for individual use. Each of these activities is aligned to national standards for science, technology, engineering, and mathematics (STEM), and the NASA messaging is current as of September 2019.

STEM Education Standards

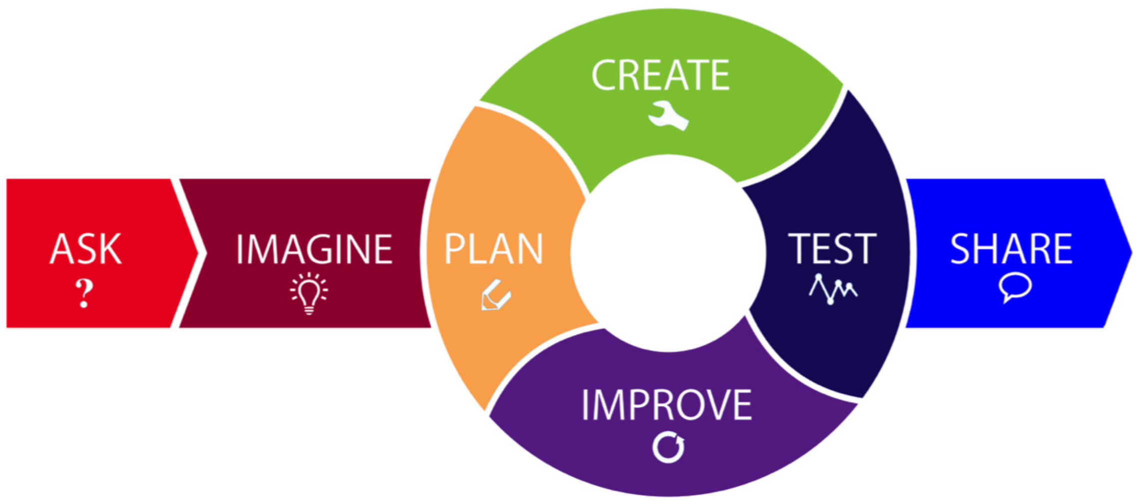
The STEM disciplines matrix shown below aligns each activity in this module to standards for teaching STEM according to four primary focus areas within each discipline. The four focus areas for science were adapted from the Next Generation Science Standards (NGSS) middle school disciplinary core ideas. 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. Find additional matrices in the Appendix: STEM Standards and Practices.

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
Assess the Structural Integrity of a Space Module				✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	
Design and Build a Space Habitat	✓			✓		✓	✓	✓	✓	✓	✓				✓	
Experiment With Water Filtration		✓		✓	✓		✓	✓		✓					✓	✓
Test Materials for Radiation Shielding	✓				✓	✓					✓					

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. The steps outlined below can be used by student teams to solve the challenges in this activity guide. Learn more about the EDP with NASA's Educator Professional Development Collaborative at https://www.txstate-epdc.net/models-of-the-engineering-design-process/.

1. ASK: Identify the problem, requirements that must be met, and the constraints that must be considered.
2. IMAGINE: Brainstorm solutions and research what others have done in the past.
3. PLAN: Select and sketch a design.
4. CREATE: Build a model or a prototype.
5. TEST: Evaluate solutions by testing and collecting data.
6. IMPROVE: Refine the design.
7. SHARE: Communicate and discuss the process and solutions as a group.



Tip: In order to manage the dynamics within each team, it may be helpful to assign each student within the group a specific task, such as materials manager, design engineer, fabrication engineer, communications specialist, or team manager. Having each team member in charge of a different element of the task may reduce internal conflict within teams.

Introduction and Background

As NASA sets its sights on returning to the Moon and preparing for Mars, it is laying the foundation for human exploration deeper into the solar system by creating an orbital outpost near the Moon called the Gateway.

Some of the Gateway features include

- Lunar communications systems
- Habitation modules containing environmental control, life support, radiation protection, and safety systems
- Science and research facilities
- Cargo stowage
- Crew and science airlocks
- Robotic and autonomous systems
- Docking capabilities
- Rendezvous sensor packages

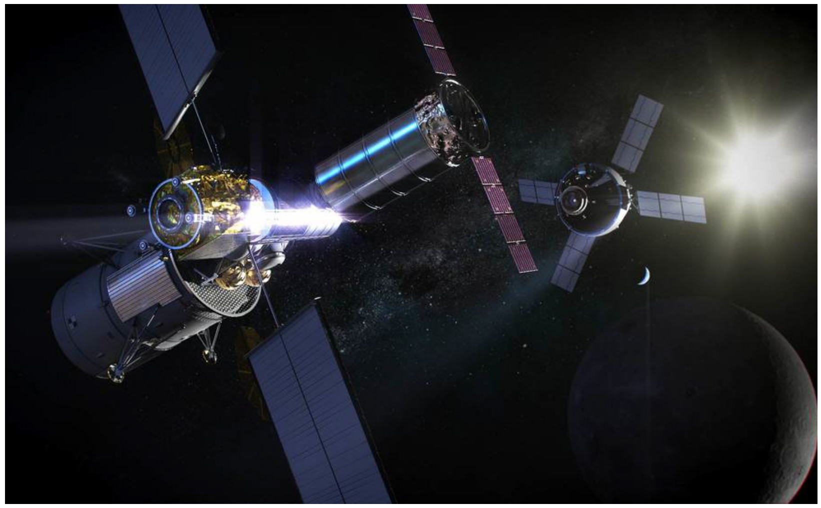


Illustration of the Gateway (left) and Orion (right). (NASA)

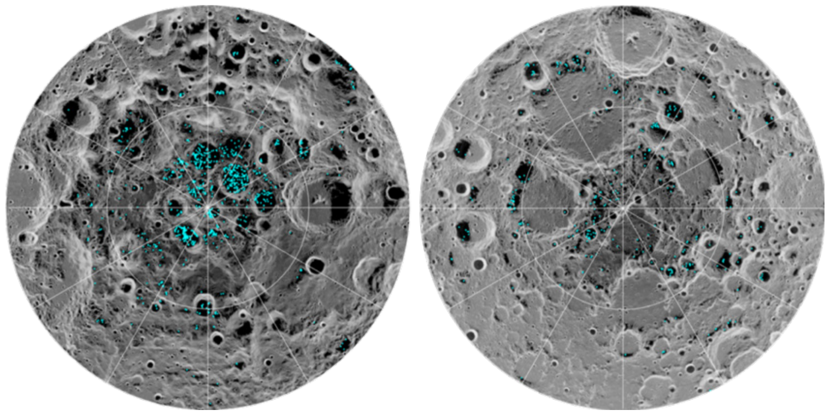
While orbiting the Moon, this spacecraft will be a temporary home and office for astronauts. The commute from Earth to the Gateway will take about 5 days and cover approximately 250,000 miles (about 400,000 kilometers). The Gateway will have living quarters, laboratories for science and research, and docking ports (physical connecting points) for visiting spacecraft. These docking ports will serve as both parking spots for the vehicles and entrances to the Gateway. The Gateway will give NASA and its partners access to more of the lunar surface than ever before, supporting both human and robotic missions.

A New Era of Lunar Exploration

NASA scientists and engineers believe the Gateway will be the key to a new era of lunar exploration—both in orbit and on the surface of the Moon. By studying the geology of the Earth, the Moon, and Mars, and the ways in which they are similar and different from each other, scientists can learn important things about how planets and planetary systems form.

NASA also wants to use the Gateway as a science platform to look back at the Earth, observe the Sun, and get unobstructed views of the vast universe. One of the unique things about the Gateway is that NASA can move it to other orbits around the Moon to do more science in new locations.

In 2009, NASA discovered that the Moon contains millions of tons of water ice. The Gateway will be able to move to the ideal position to have astronauts descend to the lunar surface and extract the ice for use in producing water, oxygen, or hydrogen. This will assist in future missions to Mars.



Distribution of surface ice at the Moon's south pole (left) and north pole (right). (NASA)

The Gateway: A Home Base for Human Missions to the Moon and Mars

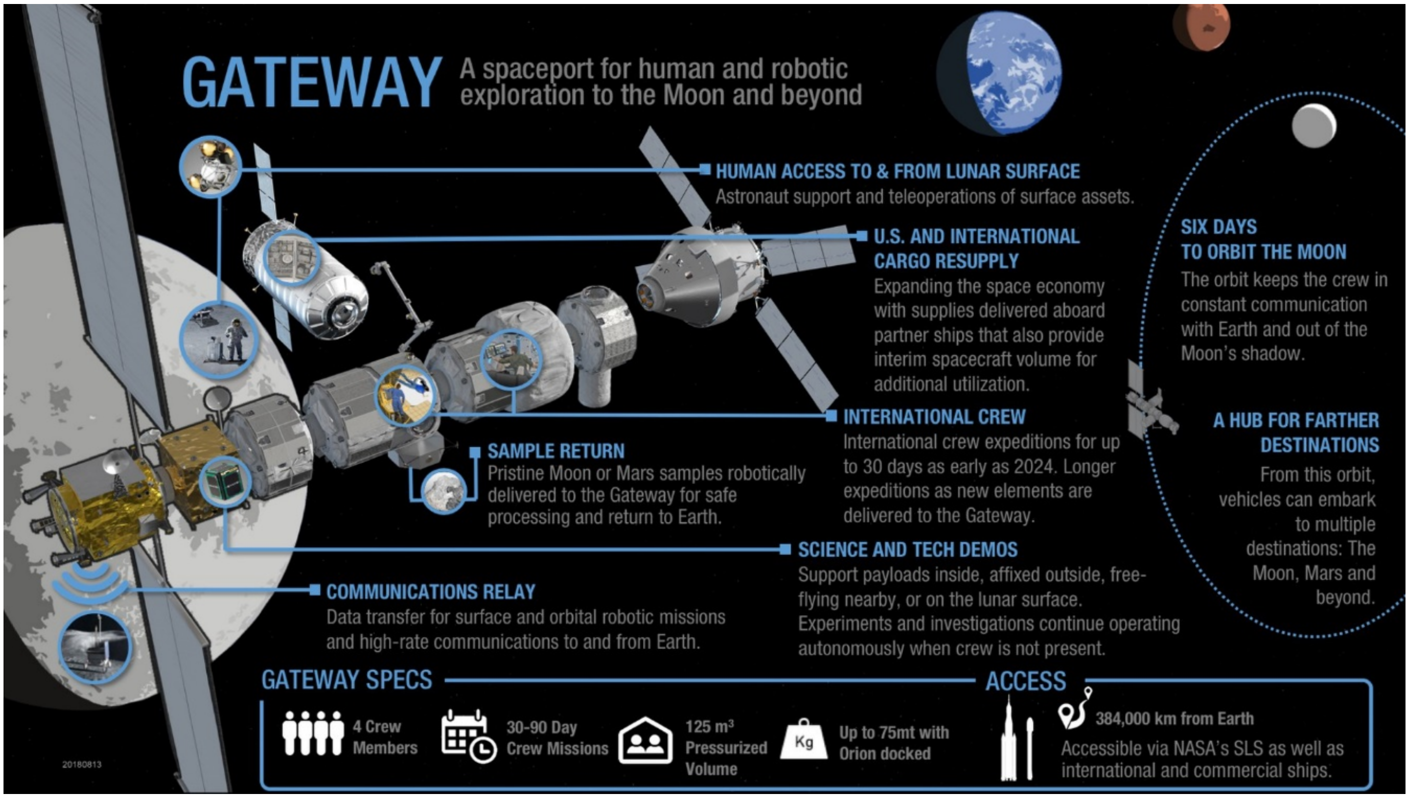
The Gateway will benefit from the years of research performed by astronauts continuously living and working on board the International Space Station since November 2000. The space station is a large spacecraft in orbit around Earth. It serves as a unique scientific platform that enables researchers from all over the world to put their talents to work on innovative experiments that could not be done anywhere else. The Gateway is similar to the space station in its design, but it will be an orbital home base for astronaut expeditions to the Moon. It will also serve as a practice ground for deep space missions—a place to train for life far away from Earth, including future human missions to Mars.

The Gateway is much smaller than the space station. Its interior is about the size of a studio apartment, whereas the space station is larger than a six-bedroom house. Once docked, astronauts can live and work aboard the Gateway for up to 3 months at a time, conduct science experiments, and take trips to the surface of the Moon. Even without a crew present, cutting-edge robotics and computers will operate experiments inside and outside the Gateway, automatically returning data back to Earth.

NASA is looking at options for astronauts to shuttle between the Gateway and the Moon on reusable landers. Just as planes use an airport on Earth, spacecraft bound for the lunar surface or for Mars can use the Gateway to refuel, replace parts, and resupply things like food and oxygen without going home first. During months-long crew expeditions to the Gateway, this could enable multiple trips down to the lunar surface and exploration of new locations on the Moon.

Building the Gateway

NASA has already started working on the Gateway. The first major Gateway part will provide power and propulsion for the spacecraft and is targeted to launch on a private rocket in 2022. After the power and propulsion element reaches orbit and test-drives its power and communications, NASA will launch four astronauts on a Space Launch System (SLS) and Orion mission carrying two new sections that will add a small living space and initial science and operational capabilities. Each year after that, astronauts will travel to the Gateway with new parts until it is fully assembled, currently targeted for 2026.



Configurations and capabilities of the Gateway. (NASA)

NASA is planning to work with U.S. companies to build a small living and working area for the Gateway called a habitation module. The addition will leverage years of research and demonstrations under Next Space Technologies for Exploration Partnerships (NextSTEP), a public-private partnership model seeking commercial development of deep space exploration capabilities to support human space flight missions. NASA is also discussing plans with international partners to provide expanded living space, advanced robotics, transportation, and science capabilities.

NASA plans to build the Gateway with just five or six rocket launches—far fewer than the 34 launches it took to build the International Space Station. NASA's powerful SLS rocket and Orion are key to the overall assembly and operations. SLS will launch the larger components for the Gateway on flights along with Orion, and Orion will be used as a tug to deliver those components to the required orbit for assembly. Together, Orion, SLS, and the Gateway represent the core of NASA's sustainable infrastructure for human exploration.

The Importance of Water Filtration

Water, essential to sustaining life on Earth, is that much more highly prized in the unforgiving realm of space travel and habitation. Given the launch cost per pound of cargo, each gallon of water at 8.33 lb (3.78 kg) quickly adds up in cost. Likewise, ample water reserves for drinking, food preparation, and bathing would take up an inordinate amount of storage space and infrastructure, which is always at a premium on a vessel or station.

Water rationing and recycling are an essential part of daily life and operations on the International Space Station and will be equally important on the Gateway. In space, where Earth's natural life support system is missing, these spaceports must provide abundant power, clean water, and breathable air at the right temperature and humidity for the duration of human habitation and with virtually no waste. NASA's Environmental Control and Life Support System (ECLSS), under continued monitoring by the Marshall Space Flight Center, helps astronauts use and reuse their precious supplies of water on the space station.

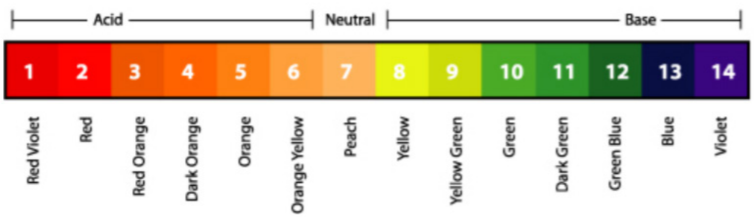
The ECLSS Water Recovery System (WRS) reclaims wastewater from humans and lab animals in the form of breath condensate (from exhaling), urine, hygiene and washing, and other wastewater streams. On Earth, biological wastewater is physically filtered by granular soil and purified as microbes in the soil break down urea, converting it to a form that plants can absorb and use to build new tissue. Wastewater also evaporates and returns as fresh rainwater—a natural form of distillation. WRS water purification machines on the space station mimic these processes, though without microbes or the scale of Earth's natural system.

The astronaut crew that will be onboard Gateway will need a system similar to WRS to efficiently recycle wastewater and reduce the need to provide the resource via resupply. Without this capability, the Gateway would not be able to support the needs of the crew during missions of up to 3 months, and resupply is not even an option for the long-duration space travel planned for future missions to Mars.

The Gateway will use filtration and temperature sterilization to ensure the water is safe to drink. During this process, water is checked often to ensure it meets water quality requirements, and it is monitored closely for bacteria, pollutants, and proper pH level. The pH scale ranges from 0 to 14 and is a tool used by scientists to measure the strength of an acid or base. Proper pH balance of 7 is important to a human body.

Public water systems must meet a pH level of 6.5 to 8.5. The space station water is required to be within the range of 6.0 to 8.5, and the same will likely be required for the Gateway. The recycled water that comes from this process is sterile, so there is no odor or bad taste.

pH COLOR CHART



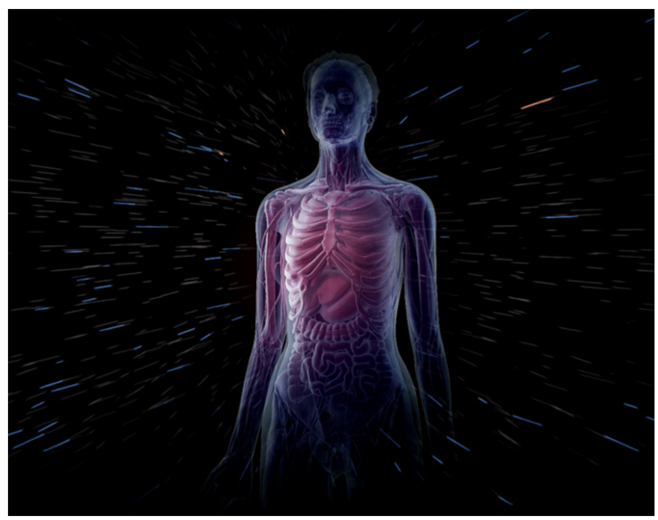
pH SCALE

Measure	Type	Examples
Below 7	Acid	Citrus juices such as lemon, orange, or lime Sodas such as cola
7	Neutral	Pure, clean water
Above 7	Base	Toothpaste, baking soda

pH color chart (left) and pH scale (right).

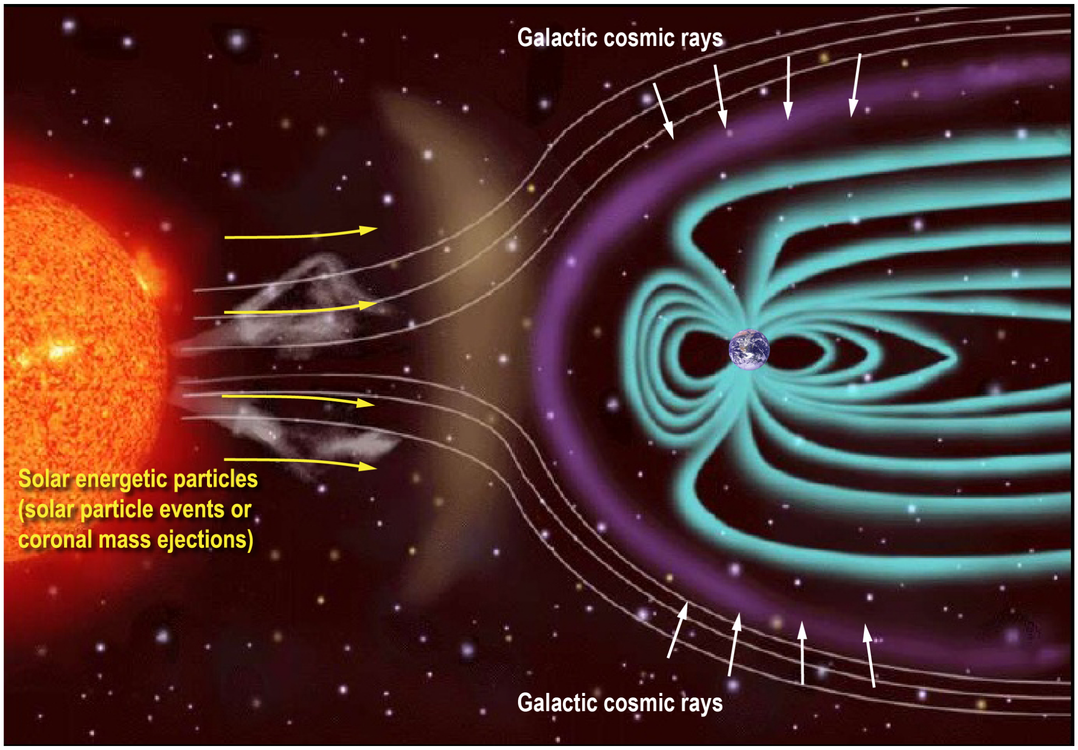
New Challenges Ahead: Radiation Shielding

Designing the Gateway presents engineers with new challenges in keeping astronauts safe and healthy while in space and after they return. As astronauts venture to interplanetary space, they will be exposed to higher levels of cosmic radiation from the Sun and galactic cosmic rays. This is called ionizing radiation because it has enough energy to knock electrons out of atoms or molecules, creating ions. Through these interactions, radiation disrupts cellular functions within the body, resulting in damage to the nervous system and producing symptoms such as nausea and fatigue. Long-term effects could include increased risks of cancer and cardiac disease.



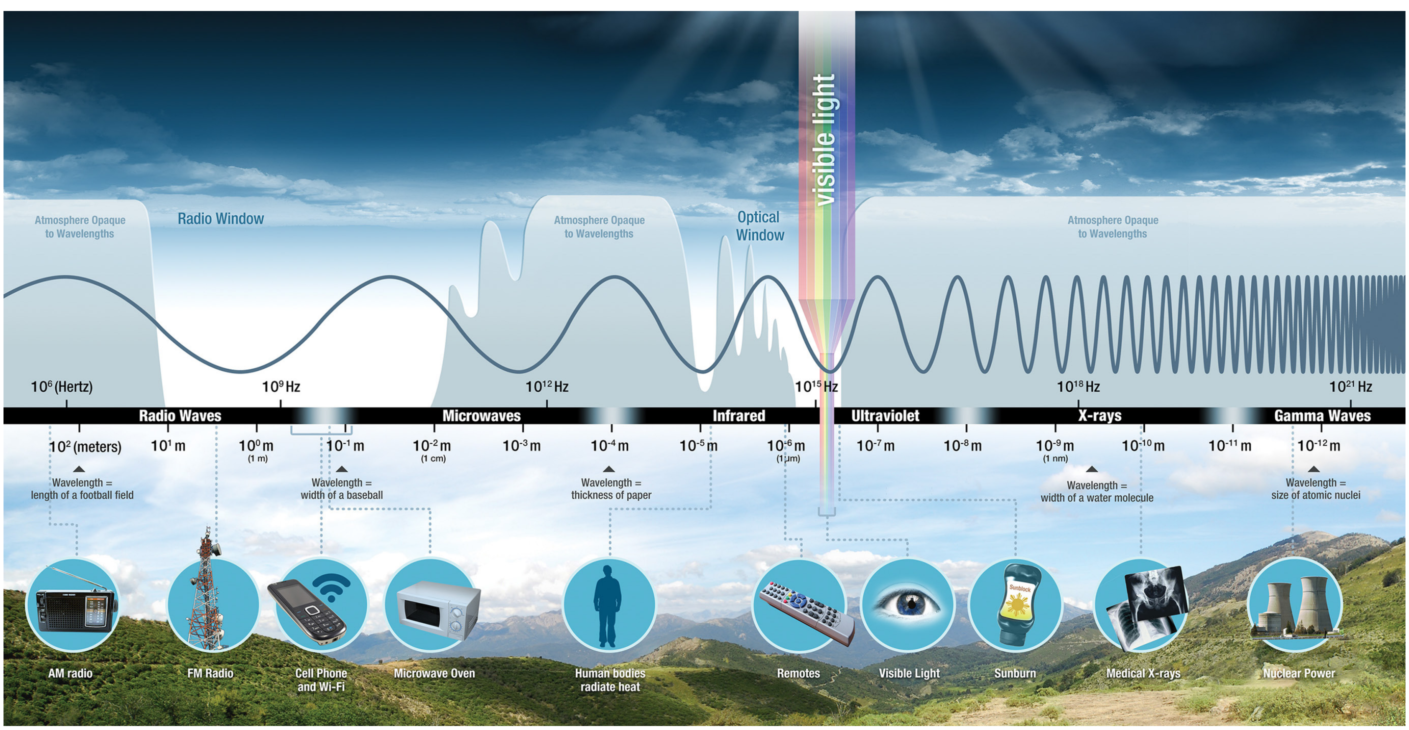
Space radiation is made up of protons and all the elements on the periodic table. It enters the human body at energies approaching the speed of light and can damage deoxyribonucleic acid (DNA). (NASA)

Earth's atmosphere and magnetosphere—the magnetic field generated by the Earth's spinning iron core—are important because they provide shielding from most of the harmful high-energy particles. On Earth, galactic cosmic radiation is intercepted by oxygen and nitrogen molecules in the atmosphere before it reaches the surface, so it is of little danger to humans. As seen in the illustration below, most of the high-energy particles from the Sun are deflected around the Earth by its magnetosphere, which extends far beyond the atmosphere.



Sources of ionizing radiation in interplanetary space. (NASA)

One form of radiation from the Sun that can have a negative impact for humans on Earth is ultraviolet (UV) radiation. UV radiation is a type of light that is invisible to the human eye because its wavelength is too short to detect. UV light is classified into three groups according to its wavelength. UVA and UVB travel through the atmosphere and can reach the Earth's surface. They cause sunburns and can lead to skin cancer. UVC is extremely dangerous, but it is completely absorbed by the ozone layer and does not reach the surface of the Earth.



Electromagnetic spectrum. (NASA)

Habitation With Gateway

The International Space Station has been hosting astronauts for the last two decades for extended stays as long as a year in length, but it has remained in low Earth orbit—just outside the atmosphere but still within the protective boundary of the Earth's magnetosphere. In contrast, the Gateway will be placed in orbit around the Moon, far from the protection of Earth's atmosphere and magnetosphere. To protect astronauts and sensitive equipment from long-term exposure to increased levels of radiation while aboard the Gateway, scientists and engineers must come up with new methods and technologies for shielding them against high-energy charged particles of galactic cosmic rays, solar particle events, and secondary protons and neutrons.

Activity One: Assess the Structural Integrity of a Space Module

Educator Notes

Challenge

Students will work as a team to design and build the skeletal structure or framework for a spaghetti space module that can support as much weight as possible.

Suggested Time

60 minutes

Learning Objectives

Students will

- Apply the steps of the engineering design process to successfully complete a team challenge.
- Design, build, and test their own space habitat module.
- Collect data after each weight test for comparison with other groups.
- Improve their model based upon the results of the experiment.
- Understand the relationship between mass and weight.

Curriculum Connection

Science and Engineering (NGSS)	
Disciplinary Core Ideas • MS-ETS1-1 Engineering Design: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions. – ETS1.A: The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. • MS-ETS1-3 Engineering and Design: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success. – ETS1.B: There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. – ETS1.C: Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. *Crosscutting Concepts* • Cause and Effect: Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.	*Crosscutting Concepts (continued)* • System and System Models: A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems. • Interdependence of Science, Engineering, and Technology: Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems. *Science and Engineering Practices* • Asking Questions and Defining Problems: A practice of science is to ask and refine questions that lead to descriptions and explanations of how the natural and designed world works and which can be empirically tested. • Develop and Use Models: A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations. • Planning and Carrying Out Investigations: Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters. • Construct Explanations and Design Solutions: The products of science are explanations and the products of engineering are solutions.
Technology (ISTE)	
Standards for Students • Innovative Designer: Students use a variety of technologies within a design process to identify and solve problems by creating new, useful, or imaginative solutions. – 4a: Students know and use a deliberate design process for generating ideas, testing theories, creating innovative artifacts or solving authentic problems. – 4c: Students develop, test, and refine prototypes as part of a cyclical design process. • Computational Thinker: Students develop and employ strategies for understanding and solving problems in ways that leverage the power of technological methods to develop and test solutions.	*Standards for Students (continued)* – 5c: Students break problems into component parts, extract key information, and develop descriptive models to understand complex systems or facilitate problem-solving. • Global Collaborator: Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally. – 7c: Students contribute constructively to project teams, assuming various roles and responsibilities to work effectively toward a common goal.
Mathematics (CCSS)	
Content Standards by Domain • CCSS.MATH.CONTENT.6.NS.B.3: Fluently add, subtract, multiply, and divide multi-digit decimals using the standard algorithm for each operation. • CCSS.MATH.CONTENT.6.SP.B.5: Summarize numerical data sets in relation to their context, such as by: – CCSS.MATH.CONTENT.6.SP.B.5.A: Reporting the number of observations. – CCSS.MATH.CONTENT.6.SP.B.5.B: Describing the nature of the attribute under investigation, including how it was measured and its units of measurement.	*Mathematical Practices:* • CCSS.MATH.PRACTICE.MP1: Make sense of problems and persevere in solving them. • CCSS.MATH.CONTENT.MP3: Construct viable arguments and critique the reasoning of others. • CCSS.MATH.PRACTICE.MP5: Use appropriate tools strategically. • CCSS.MATH.PRACTICE.MP6: Attend to precision.

Preparation Time

15 minutes

- Read the Introduction and Background, Educator Notes, and Student Handout to become familiar with the activity.
- Gather and prepare all supplies listed on the materials list.
- If using a glue gun, even with cool-melt glue, set up a glue gun station for safety and supervision.
- Print copies of the Student Handout for each team.
- If presenting videos or web-based resources, test the links and the classroom technology ahead of time.
- Determine the internal volume constraint for the space module in advance of the lesson. Any lightweight cylinder, ranging in size from a toilet paper tube to a 12-oz aluminum can, will work.

Materials

- ☐ Toilet paper tubes, aluminum cans, or similar lightweight cylinders (1 per team for use as a volume constraint)
- ☐ 30 pieces of uncooked spaghetti for each team
- ☐ Clear tape or low-temperature glue gun with cool-melt glue (Note: teams will have limited quantities per challenge constraints)
- ☐ Index cards
- ☐ Mass (lead weights, coins, large washers, or similar)
- ☐ Scissors
- ☐ Metric scale
- ☐ Rulers
- ☐ Paper and pencils for brainstorming
- ☐ Copies of Student Handout and blank paper

Introduce the Challenge

- Provide context for this activity using the Introduction and Background information in this guide. Discuss the different types of modules in a space habitat.
- Engage students with the following discussion questions:
  - Why is a space habitat made up of individual modules?
  - Why is it important for modules to be hollow with as much open space inside as possible?
  - If a space habitat orbits in a microgravity environment, why does it need to be lightweight?
  - What are some safety concerns or consequences of a module that is not structurally strong?
  - What types of forces do modules experience on Earth, during launch, during assembly, and while in use?
- Explain the role of engineers in designing technology to solve problems. Share the NASA for Kids video [Intro to Engineering] and introduce the engineering design process.
- Divide the class into teams of three to five students and pass out the Student Handout to each team. Use the handout to explain the details of the challenge, including the design constraints and your expectations for teamwork and classroom management.

Share With Students

Brain Booster

NASA is looking at options for astronauts to shuttle between the Gateway and the Moon on reusable landers. Just as planes use an airport here, spacecraft bound for the lunar surface or for Mars can use the Gateway to refuel, replace parts, and resupply things like food and oxygen without going home first.

Learn more: https://appel.nasa.gov/2019/06/06/nasa-selects-partners-for-lunar-lander-development/

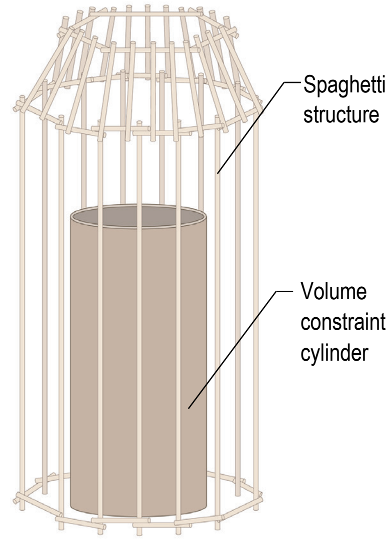
On Location

The Marshall Space Flight Center in Huntsville, Alabama, will manage NASA's plans to build a lunar landing system that will carry the next man and the first woman to the surface of the Moon by 2024. Check out Touchdown, an engineering design challenge for students to investigate gravity, motion, and forces to design and build a shock-absorbing system for a lunar lander.

Touchdown Activity: https://www.nasa.gov/stem-ed-resources/otm-touchdown.html

Design Constraints

1. The volume constraint cylinder must fit completely and securely within the spaghetti structure each team builds. It cannot be attached to the structure with tape or any other means; it must remain loose within the structure without falling out.
2. Teams are only allowed to use the supplies provided. If they make a mistake or change their design, they **cannot** trade in used tape, glue sticks, or broken spaghetti pieces for more, nor can they trade materials with another team. Instead, they must recycle used materials into their design.
3. The module frame will be tested standing upright on its end (oriented like a soda can), and there should be a gap between the top of the volume constraint cylinder and the spaghetti structure.



Facilitate the Challenge

Ask, Imagine, and Plan

- Answer any questions teams have about the challenge or design constraints.
- Consider requiring teams to submit their design for review before allowing them to collect building materials.

Create

- In the first phase of the challenge, teams may only use 25 pieces of uncooked spaghetti and 50 cm of tape or one small glue stick to design and build the skeletal structure or framework of a space habitat module.
- In order for the interior of their module to remain open for "usable" space, the framework must be built around the cylindrical volume size constraint. The cylinder (toilet paper tube or aluminum can) must be loose within the framework and not attached in any way.

Test and Improve

1. Each team will test the strength of their design by placing it upright on its end (oriented like a soda can) and gradually adding weights until the structure "fails." The structure has "failed" when it meets any of the following three criteria:
   - Any piece of spaghetti has broken/snapped.
   - Any end of a piece of spaghetti has become detached from the tape or glue.
   - Any piece of spaghetti has bent to the point that it touches the top of the volume constraint cylinder.
2. After the first weight failure test, students will measure and record the mass that was necessary to cause their module structure to fail. In the second phase of the challenge, teams will receive five additional pieces of spaghetti and an additional 10 cm of tape (no additional glue) to repair and improve their design.
3. After their improved design is complete, students will again test their module structures to failure. Their goal is to increase the mass that their structure can support by 50 percent.

Share

Allow teams time to share their designs with the class. Engage students with the following discussion questions:

- What was the greatest challenge for your team today? How did you address this challenge?
- Which was most difficult: Keeping the spaghetti from bending, breaking, or becoming detached?
- What was the purpose of the design constraints? Why were you limited in how much the spaghetti could bend?
- Would this challenge be more difficult with a larger or smaller cylinder used as a size constraint? Why?

Northrop Grumman Innovation Systems has proposed a Gateway module design based on its Cygnus cargo spacecraft, pictured here. (NASA)

Extensions

- Add a cost constraint to the challenge and create a budget for your students to “purchase” materials. Assign cost to each piece of spaghetti and centimeter of tape. Challenge students to create the most efficient design (smallest ratio of cost to mass supported).
- Repeat the challenge using different materials for the structure.

References

Modified from the following activities:
Spaghetti Anyone? Building With Pasta. https://www.jpl.nasa.gov/edu/teach/activity/spaghetti-anyone/
NASA Engineering Design Challenges: Spacecraft Structures. https://www.nasa.gov/pdf/361814main_EP_2009_06_115_MSFC.pdf

Additional Resource

- Digital Badging: Online NASA STEM Learning. https://www.txstate-epdc.net/digital-badging/

Activity One: Assess the Structural Integrity of a Space Module

Student Handout

Your Challenge

Design and build the skeletal structure or framework for a spaghetti space module that can support as much weight as possible.

Design Constraints

1. The volume constraint cylinder provided by your teacher must fit completely and securely inside the spaghetti structure you build. It cannot be attached to the spaghetti structure with tape or any other means. It must stay loose inside your structure, and it cannot fall out.
2. You are only allowed to use the supplies provided by your teacher. If you make a mistake or change your design, you **cannot** trade in used tape, glue sticks, or broken spaghetti pieces for more, and you **cannot** trade materials with another team. Instead, you must recycle used materials into your design.
3. Your module frame will be tested standing upright on its end (oriented like a soda can). When you place the module on its end, there should be a gap between the top of the volume constraint cylinder and your spaghetti structure.

Ask, Imagine, and Plan

- Discuss different design and assembly methods for your module.
- What are the strengths and weaknesses of the materials provided in the challenge?
- How can you best use the limited number of supplies?
- What are some design elements that you can include in your design to maximize strength?
- Sketch your module design on the paper provided by your teacher. Remember to include the volume constraint cylinder.

Create

Your team will build a skeletal structure or framework for a space module using only the materials provided. It must be constructed around the provided volume constraint cylinder, which represents the interior "usable" space of the module.

Test and Improve

1. After building your module, you will test its strength using a weight failure test. Write down any observations about how your structure performs during the test.
2. **Weight failure test:** Place your module upright on one end (oriented like a soda can) and place a single index card on top. Slowly add mass on top of the card until your structure fails in one of the following ways:
   - Any piece of spaghetti has broken/snapped
   - Any piece of spaghetti has become detached from the tape or glue
   - Any piece of spaghetti has bent to the point that it touches the top of the volume constraint cylinder
3. After your structure has reached its failure point, measure the mass you added and record the mass in grams on your brainstorming paper.

Fun Fact

Practice makes perfect! The Gateway will be a home base for astronaut expeditions on the Moon and future human missions to Mars. Even before the first trip to Mars, astronauts will use the Gateway to train for life far away from Earth.

Learn more: https://www.youtube.com/watch?v=YOG3tAkPpPE

Career Corner

Geology is the study of rocks, and geologists are the people who study them. There are different types of geologists. Planetary geologists at NASA study planets and their moons, asteroids, comets, and meteorites. NASA wants to use the Gateway as a science platform to look back at the Earth, observe the Sun, and get unobstructed views of the vast universe. By studying the geology of the Earth, the Moon, and Mars, we can learn important things about how planets and planetary systems form!

Learn more: https://solarsystem.nasa.gov/people/500/phil-christensen/

4. Now it is time to repair and improve your design. The goal for your redesign is to hold 50 percent more mass than your previous weight failure test. Calculate your goal by multiplying the mass from the first test by 1.5 and record on your paper.
5. You must reuse the existing structure, but you will receive five additional pieces of spaghetti and another 10 cm of tape (no additional glue). Recall what caused your design to eventually fail. Discuss what improvements you can make based on your experience and your new materials.
6. Sketch your module redesign on your paper. Be sure to indicate where you made design improvements and why.
7. Make the indicated changes to your existing structure.
8. Repeat the weight failure test with your redesigned module structure, slowly adding mass until it fails. On your paper, record the mass in grams for the second weight failure test.

Share

- What improvements did you make to the structure of your module based on your first test?
- Did you meet your goal of supporting 50 percent more weight in the second test? Describe the results.
- As you compare the various team designs, what characteristics did the most successful structures have in common?
- If you could repeat the experiment, what changes would you make to your structure?

Activity Two: Design and Build a Space Habitat

Educator Notes

Challenge

Students will work as a team to design and build a model of a space habitat using the engineering design process.

Suggested Time

90 to 120 minutes
(Two full activity periods)

Learning Objectives

Students will

- Apply the steps of the engineering design process to successfully complete a team challenge.
- Design and build their own space habitat.
- Test their design, make observations, and collect data for analysis.
- Improve their model based upon the results of the experiment.

Curriculum Connection

<table>
<tr><th colspan="2">Science and Engineering (NGSS)</th></tr>
<tr><td>
Disciplinary Core Ideas

MS-PS2-1 Motion and Stability: Forces and Interactions: Apply Newton's third law to design a solution to a problem involving the motion of two colliding objects.
MS-ETS1-1 Engineering Design: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
ETS1.A: Defining and Delimiting Engineering Problems: The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.
MS-ETS1-3 Engineering Design: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
ETS1.B: Developing Possible Solutions: There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.
ETS1.C: Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design.

</td><td>
Crosscutting Concepts

Cause and Effect: Cause and effect relationships may be used to predict phenomena in natural or designed systems.
Systems and System Models: Models can be used to represent systems and their interactions—such as inputs, processes, and outputs—and energy and matter flows within systems.
Interdependence of Science, Engineering, and Technology: Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems.

Science and Engineering Practices

Asking Questions and Defining Problems: A practice of science is to ask and refine questions that lead to descriptions and explanations of how the natural and designed world works and which can be empirically tested.
Developing and Using Models: A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations.
Planning and Carrying Out Investigations: Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters.

</td></tr>
<tr><th colspan="2">Technology (ISTE)</th></tr>
<tr><td>
Standards for Students

Innovative Designer: Students use a variety of technologies within a design process to identify and solve problems by creating new, useful, or imaginative solutions.
4a: Students know and use a deliberate design process for generating ideas, testing theories, creating innovative artifacts, or solving authentic problems.
4c: Students develop, test, and refine prototypes as part of a cyclical design process.
4d: Students exhibit a tolerance for ambiguity, perseverance, and the capacity to work with open-ended problems.

</td><td>
Standards for Students (continued)

Computational Thinker: Students develop and employ strategies for understanding and solving problems in ways that leverage the power of technological methods to develop and test solutions.
5c: Students break problems into component parts, extract key information, and develop descriptive models to understand complex systems or facilitate problem-solving.
Global Collaborator: Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally.
7c: Students contribute constructively to project teams, assuming various roles and responsibilities to work effectively toward a common goal.

</td></tr>
<tr><th colspan="2">Mathematics (CCSS)</th></tr>
<tr><td>
Content Standards by Domain

CCSS.MATH.CONTENT.6.SP.B.5: Summarize numerical data sets in relation to their context, such as by:
CCSS.MATH.CONTENT.6.SP.B.5.A: Reporting the number of observations.
CCSS.MATH.CONTENT.6.SP.B.5.B: Describing the nature of the attribute under investigation, including how it was measured and its units of measurement.
CCSS.MATH.CONTENT.7.G.B.6: Solve real-world and mathematical problems involving area, volume and surface area of two- and three-dimensional objects composed of triangles, quadrilaterals, polygons, cubes, and right prisms.

</td><td>
Mathematical Practices:

CCSS.MATH.PRACTICE.MP1: Make sense of problems and persevere in solving them.
CCSS.MATH.PRACTICE.MP3: Construct viable arguments and critique the reasoning of others.
CCSS.MATH.PRACTICE.MP5: Use appropriate tools strategically.
CCSS.MATH.PRACTICE.MP6: Attend to precision.

</td></tr>
</table>

Preparation Time

15 to 30 minutes for setup, but several days to collect building materials

- Read the Introduction and Background, Educator Notes, and Student Handout to become familiar with the activity.
- Gather and prepare all supplies listed on the materials list.
- If using a glue gun, even cool-melt glue, set up a glue gun station for safety and supervision.
- Print copies of the Student Handout for each team.
- If presenting videos or web-based resources, test the links and the classroom technology ahead of time.

Materials

- ☐ Copies of Student Handout and blank paper
- ☐ Meterstick
- ☐ Paper and pencil for brainstorming
- ☐ Scissors
- ☐ Stapler and staples
- ☐ Tape
- ☐ White glue

Note: This activity also requires a large variety of building materials that can be obtained from craft scraps and recyclable materials—use your imagination! It is advised to start collecting these materials several days in advance.

The following are some suggested materials.

- ☐ Aluminum foil
- ☐ Balloons
- ☐ Bamboo skewers
- ☐ Bubble wrap
- ☐ Buttons or beads
- ☐ Cardboard scraps
- ☐ Cardboard tubes
- ☐ Foil plates
- ☐ Paper bags
- ☐ Paper clips
- ☐ Pipe cleaners
- ☐ Plastic bottles
- ☐ Plastic cups
- ☐ Popsicle sticks
- ☐ Straws
- ☐ String

Introduce the Challenge

- Provide context for this activity using the Introduction and Background information in this guide. Discuss the different types of modules in a space habitat and the types of forces they might experience during launch and assembly.
- Explain the role of engineers in designing technology to solve problems. Share the NASA for Kids video Intro to Engineering and introduce the engineering design process.
- Divide the class into teams of three to five students and pass out the Student Handout to each team. Use the handout to explain the details of the challenge, including the design constraints and your expectations for teamwork and classroom management.

Share With Students

Brain Booster

The Gateway will be much farther from Earth's surface than the International Space Station, which orbits an average of 400 km (250 miles) above our planet. The Gateway will be about 1,500 km (930 miles) above the Moon's surface at its closest approach. The space station orbits Earth in about 90 minutes, completing nearly 16 orbits per day, but the Gateway will take 8,640 minutes, or 6 days, to orbit the Moon once! This 6-day orbit will keep the Gateway out of the Moon's shadow at all times, allowing constant communication with Earth and enabling the Gateway to serve as an outpost for both lunar surface and future deep space missions.

Learn more: https://www.nasa.gov/topics/moon-to-mars/lunar-gateway

On Location

NASA's Goddard Space Flight Center in Greenbelt, Maryland, is playing a vital role in the areas of communications and instrument development to advance spacecraft-based instruments and laser communication capabilities for use in lunar landing missions.

Learn more: https://www.nasa.gov/feature/goddard/2019/goddard-technologists-and-scientists-prepare-for-a-new-era-of-human-exploration

Design Constraints

The space habitat must contain the following five modules:

1. Power and propulsion module with solar panels and thrusters
2. Habitation module with an exterior docking port
3. Laboratory module with an exterior docking port
4. Storage module with two exterior docking ports
5. Airlock module with an external hatch

In addition to the five modules, the following must be attached to the outside of the spacecraft:

1. Robotic arm to assist in construction and docking
2. Communications array for contacting Earth, a ground station, or other spaceships
3. Instrument package to study a nearby planet or moon

Testing Requirements

1. **Drop test**: To ensure that the five modules can withstand the stress of launching into space, each one must "survive" a drop test with no structural damage from a height of 1 m in order to be certified for assembly and installation to the space habitat. If any components break or fall off, teams must improve the design and test again.
2. **Volume constraint**: To ensure that the space habitat does not exceed the volume constraint, the entire space habitat cannot be more than 1 m high, 1 m long, or 1 m wide.
3. **Structural strength test**: To ensure that the space habitat will stay together in orbit, the completed model must undergo a structural strength test. Once it has been assembled, a team member must be able to hold it with one hand without any modules or other pieces falling off.

Facilitate the Challenge

Ask

- Answer any questions students have about the challenge or design constraints.

Imagine

- Allow students to view the available building materials before they begin planning.

Plan

- Consider requiring teams to submit their design for review before allowing them to collect building materials.

Create, Test, and Improve

- Go over classroom safety and management of the supplies before teams begin building and testing.
- Do not discourage failure, as testing and improving are part of the engineering design process.
- Ask guiding questions to help teams analyze how to apply STEM concepts to improve their design before testing again.

Safety: Students will likely be using scissors to cut irregularly shaped materials. Ensure that they are using safe cutting practices. If using glue guns, make sure the glue gun station is monitored at all times.

Share

- Allow each team an opportunity to present their model to the rest of the class.
- Engage students with the following discussion questions:
  - What challenges did your team face when completing this activity?
  - After completing the activity, what would you change about your original design?
  - What types of challenges do you think engineers are facing while designing and building components of a space habitat for NASA?

Extensions

- Challenge students to use leftover materials to create spacecraft and landing vehicles that can dock with their space habitat.
- Add a cost constraint to the challenge and create a budget for students to "purchase" materials. Assign cost to all materials based on mass, area, or type of material.

Reference

Modified from Build a Satellite to Orbit the Moon activity in NASA's BEST Students: Beginning Engineering, Science, and Technology. https://www.nasa.gov/pdf/530250main_6to8NBSGuide.pdf

Additional Resources

- Rocket Science Ride to Station (includes simulated docking activity for students). https://rocketsciencec2e.ksc.nasa.gov/
- Digital Badging: Online NASA STEM Learning. https://www.txstate-epdc.net/digital-badging/

Activity Two: Design and Build a Space Habitat

Student Handout

Your Challenge

Work as a team to design and build a model of a space habitat using the engineering design process.

Design Constraints

The space habitat must contain the following five modules:

1. Power and propulsion module with solar panels and thrusters
2. Habitation module with an exterior docking port
3. Laboratory module with an exterior docking port
4. Storage module with two exterior docking ports
5. Airlock module with an external hatch

In addition to the five modules, the following must be attached to the outside of the spacecraft:

1. Robotic arm to assist in construction and docking
2. Communications array for contacting Earth, a ground station, or other spaceships
3. Instrument package to study a nearby planet or moon

Testing Requirements

1. **Drop test**: To ensure that the five modules can withstand the stress of launching into space, each one must "survive" a drop test with no structural damage from a height of 1 m in order to be certified for assembly and installation to your space habitat. If any components break or fall off, improve your design and test again.
2. **Volume constraint**: To ensure that the space habitat does not exceed the volume constraint, the entire space habitat cannot be more than 1 m high, 1 m long, or 1 m wide.
3. **Structural strength test**: To ensure that your space habitat will stay together in orbit, your model must undergo a structural strength test. Once your habitat has been assembled, you must be able to hold it with one hand without any modules or other pieces falling off.

Ask

- Does your team know what they are expected to design and build?
- Does your team understand the design constraints?
- What questions does your team have about today's challenge?

Imagine

- Look over the building materials and supplies provided by your teacher. As a team, discuss and imagine how each of the materials can be used to build the parts of a space habitat. Make a list of a few of your ideas on the paper provided by your teacher.

Plan

- Draw your team's design for a space habitat model on the paper provided by your teacher.
- Make sure to label each of the five modules: power and propulsion, habitat, laboratory, storage, and airlock. Refer back to the **Design Constraints** section to review what is required for each module.
- Make sure to include the robotic arm, communications array, and instrument package.

Fun Fact

Illustrations of the Earth and the Moon often make them look really close together. Don't be fooled! They are actually really far apart. The Moon is an average of 384,400 km (238,855) away from Earth. How far away is that? That's about 30 Earth diameters away.

Learn more: https://spaceplace.nasa.gov/moon-distance/en/

Career Corner

How about a career in aerospace engineering? Modern spacecraft design requires the use of sophisticated computer equipment and software design tools, modeling, and simulations for tests, evaluation, and training. A 4-year bachelor's degree is the minimum necessary to enter this field. Colleges and universities also offer graduate programs where students can earn master's and doctoral degrees. The annual median wage for aerospace engineers is over $100,000!

Learn more: https://www.youtube.com/watch?time_continue=9&v=bnxcib-8S4s

Create, Test, and Improve

1. Build and test each module individually. Modules will not be attached to each other until after the team has successfully completed each drop test.
2. **Drop test**: Create a Drop Test Notes and Observations table on the paper provided by your teacher. Use the table below as an example. Drop each of the five modules from a height of 1 m and fill in the information on your table. Note any modules that were damaged and discuss as a team what adjustments could be made to improve the design and prevent damage during retesting.

Drop Test Notes and Observations		
Module Tested	**Describe Any Damage**	**Suggested Improvements**
Power and Propulsion		
Habitation		
Laboratory		
Storage		
Airlock		

3. Once all modules have successfully completed the Drop Test, assemble the modules according to the team's design. Additional materials may be added to strengthen the connection between each module. Remember to attach your robotic arm, communications array, and instrument package.
4. **Volume constraint:** Create a Volume Notes table on your paper like the example below. Using a meterstick, measure the length, width, and height of your completed space habitat in centimeters. Record the measurements in the table on your paper.

Volume Notes	
Dimensions	**Measurement, cm**
Length	
Width	
Height	

5. Are any of your measurements longer than 1 m (100 cm)? If so, how can the modules be rearranged so the space habitat is within the design constraints? List any design changes the team makes to comply with the design restraints on your paper.
6. **Structural strength test:** Using only one hand, pick up your space habitat model. When lifted, do any of the modules or other pieces fall off? If so, make a list, noting each item and the team's plan to reattach and make it stronger.

Share

- What challenges did your team face when completing this activity?
- After completing the activity, what would you change about your original design?
- What types of challenges do you think engineers are facing while designing and building components of a space habitat for NASA?
- Be prepared to discuss your design with the class.

Activity Three: Experiment With Water Filtration

Educator Notes

Challenge

Students will work as a team to create a water filtration system using an assortment of materials that will produce filtered water with a pH level of 6.5 to 8.5.

Suggested Time

60 minutes

Learning Objectives

Students will

- Measure length and volume using metrics.
- Demonstrate teamwork and communication skills to perform a task.

Curriculum Connection

<table>
<tr><th colspan="2">Science and Engineering (NGSS)</th></tr>
<tr>
<td>Disciplinary Core Ideas
• MS-ETS1-2 Engineering Design: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
– ETS1.B: Developing Possible Solutions: There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.
• MS-ETS1-4 Engineering Design: 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.
– ETS1.B: Developing Possible Solutions: A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. Models of all kinds are important for testing solutions.
– ETS1.C: Optimizing the Design Solution: The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution.
• MS-LS2-1 Ecosystems: Interactions, Energy, and Dynamics: Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem. Emphasis is on cause and effect relationships between resources and growth of individual organisms and the numbers of organisms in ecosystems during periods of abundant and scarce resources.
– LS2.A: Interdependent Relationships in Ecosystems: Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors. In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction. Growth of organisms and population increases are limited by access to resources.
• MS-LS2-5 Ecosystems: Interactions, Energy, and Dynamics: Evaluate competing design solutions for maintaining biodiversity and ecosystem services
– LS4.D: Biodiversity and Humans: Changes in biodiversity can influence humans' resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on—for example, water purification and recycling</td>
<td>Disciplinary Core Ideas (continued)
– ETS1.B: Developing Possible Solutions: There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.
Crosscutting Concepts
• Cause and Effect: Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.
• Stability and Change: For both designed and natural systems, conditions that affect stability and factors that control rates of change are critical elements to consider and understand.
• Influence of Science, Engineering, and Technology on Society and the Natural World: All human activity draws on natural resources and has both short- and long-term consequences, positive as well as negative, for the health of people and the natural environment.
Science and Engineering Practices
• Develop and Using Models: A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations.
• Analyzing and Interpreting Data: Scientific investigations produce data that must be analyzed in order to derive meaning. Because data patterns and trends are not always obvious, scientists use a range of tools—including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data. Scientists identify sources of error in the investigations and calculate the degree of certainty in the results. Modern technology makes the collection of large data sets much easier, providing secondary sources for analysis.
• Engaging in Argument from Evidence: Argumentation is the process by which explanations and solutions are reached.</td>
</tr>
<tr><th colspan="2">Technology (ISTE)</th></tr>
<tr>
<td>Standards for Students
• Knowledge Constructor: Students critically curate a variety of resources using digital tools to construct knowledge, produce creative artifacts, and make meaningful learning experiences for themselves and others.
– 3d: Students build knowledge by actively exploring real-world issues and problems, developing ideas and theories and pursuing answers and solutions.
• Computational Thinker: Students develop and employ strategies for understanding and solving problems in ways that leverage the power of technological methods to develop and test solutions.</td>
<td>Standards for Students (continued)
– 5c: Students break problems into component parts, extract key information, and develop descriptive models to understand complex systems or facilitate problem-solving.
• Global Collaborator: Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally.
– 7c: Students contribute constructively to project teams, assuming various roles and responsibilities to work effectively toward a common goal.</td>
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<tr><th colspan="2">Mathematics (CCSS)</th></tr>
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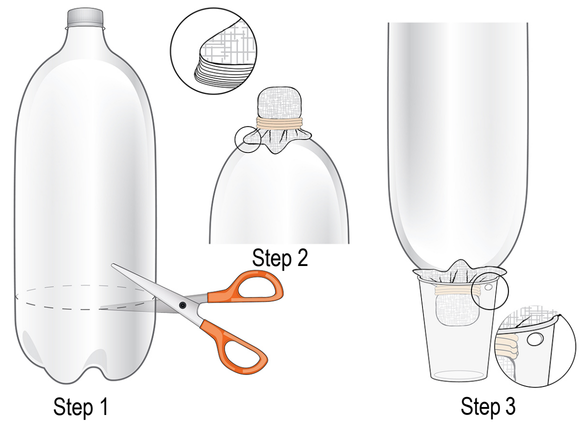
<td>Content Standards by Domain
• CCSS.MATH.CONTENT.6.SP.B.5: Summarize numerical data sets in relation to their context, such as by:
– CCSS.MATH.CONTENT.6.SP.B.5.A: Reporting the number of observations.
– CCSS.MATH.CONTENT.6.SP.B.5.C: Giving quantitative measures of center (median and/or mean) and variability (interquartile range and/or mean absolute deviation), as well as describing any overall pattern and any striking deviations from the overall pattern with reference to the context in which the data were gathered.</td>
<td>Mathematical Practices:
• CCSS.MATH.PRACTICE.MP2: Reason abstractly and quantitatively.
• CCSS.MATH.PRACTICE.MP3: Construct viable arguments and critique the reasoning of others.
• CCSS.MATH.PRACTICE.MP5: Use appropriate tools strategically.
• CCSS.MATH.PRACTICE.MP6: Attend to precision.</td>
</tr>
</table>

Habitation With Gateway

Preparation Time

45 minutes

- Read the Introduction and Background, Educator Notes, and Student Handout to familiarize yourself with the activity.
- Print copies of the Student Handout for each team.
- Gather and prepare all supplies listed on the materials list. Instructions for the water filtration system structure and the gray water follow here.
  - **Water filtration system structure**: Construct a water filtration system structure for each team of three to four students. (Structures can be reused in subsequent class periods.)
    1. Cut off the bottom of the 2-liter bottle, just above the curve.
    2. Cover the mouth of the bottle with at least 10 layers of cheesecloth and secure with a rubberband.
    3. Punch a hole just below the rim of each of the 4 large plastic cups. This will allow air pressure to escape as water drips into the cups.



  - **Gray water**: Make enough gray water for each team to have its own 600-mL supply (100 mL of Italian salad dressing mixed with 500 mL of water).
    1. Test your tap water before making the gray water solution. Your clean water should have a pH level between 6.5 and 7.5. If your tap water's pH level is not between pH 6.5 and 7.5, use store-bought drinking water.
    2. Mix 1 part Italian salad dressing to 5 parts water in a large, clean container.
    3. Ensure that the pH level of the gray water is about 4. If not, add vinegar until the pH tests to about 4.

Materials

Per student:
- ☐ Safety glasses
- ☐ Copies of Student Handout and blank paper

Per group (3 to 4 students):
- ☐ Water filtration system structure
  - ☐ 2-liter bottle
  - ☐ 10 layers of cheesecloth
  - ☐ Rubberbands
- ☐ 600 mL of gray water
  - ☐ Italian dressing
  - ☐ Tap water or bottled water with a pH level of 6.5 to 7.5
  - ☐ Optional: Vinegar
- ☐ 600 mL of clean water with a pH level of 6.5 to 7.5
- ☐ Metric liquid measuring cup
- ☐ Metric ruler
- ☐ 5 litmus paper strips
- ☐ pH color chart
- ☐ 4 large, clear plastic cups with a hole punched just below the rim
- ☐ 3 paper plates
- ☐ Mesh bag
- ☐ Assorted materials for filtration layers
  - ☐ Aquarium gravel
  - ☐ Play sand
  - ☐ Activated carbon/activated charcoal
  - ☐ Marbles
  - ☐ Cotton balls
  - ☐ Coffee filters, wadded up
  - ☐ Packing materials (Styrofoam™ packaging, packing peanuts, etc.)

Introduce the Challenge

- Discuss with students the importance of water filtration devices to produce clean water both here on Earth and in space.
  - How are processes for recycling water on Earth and in space the same or different?
- Review the concept of pH with students, including base, neutral, and acid.
- Explain the steps for testing pH using litmus paper and pH color charts.
- Define safe pH levels for drinking water. In the United States, public water systems must meet a pH level of 6.5 to 8.5.
- Challenge students to create and test water filtration devices to produce clean water with a pH level of 6.5 to 8.5 using three different types of filtration materials.

Facilitate the Challenge

Ask and Imagine

Engage students with the following discussion questions:

- Why would water filtration devices be crucial to future deep space exploration missions?
- How is water filtered for use on Earth? Where do you get your drinking water?
- Where is potable (safe for drinking) water a problem on Earth?
- Why is it important to run a control test?

Plan

- Each team will choose three types of filtration materials to create their water filtration device.
  - Each chosen material will become a 5- to 8-cm filtration layer within the water filtration system. Note: Some materials may need to be compacted when placed in the water filtration system.
- Teams should use the blank paper to sketch their design and document their plan to build a water filtration device.

Create and Test

1. Teams must follow their plan and design to create their water filtration device.
2. Each team will conduct a control trial and document the results.
3. Next, teams will record their predictions, observations, and results for the functionality and pH level of the water produced by their water filtration system for three experimental trials on the blank paper.

Share

Engage students with the following discussion questions:

- What was the greatest challenge for your team today? How did you address this challenge?
- How did the function of your water filtration device change throughout the trials?
- Which filtration material do you think worked best? Why?
- If you were to create another water filtration device, what would you do differently?
- If your device was used in space instead of on Earth, what would you have to modify? Why?

Extensions

- Add another iteration of the design challenge for teams to create a new water filtration device using what they learned from the first iteration.
- Add another iteration of the design challenge for teams to create a new water filtration device using different materials or a different filtration layer thickness.
- Ask teams to retest their previously filtered water through their water filtration device.
  - Does repeating the filtration process further clean the water?

Reference

Modified from NASA Engineering Design Challenges: Environmental Control and Life Support Systems Water Filtration Challenge.
https://www.nasa.gov/pdf/280748main_Water_Filtration_Guide.pdf

Additional Resource

- Digital Badging: Online NASA STEM Learning. https://www.txstate-epdc.net/digital-badging/

Share With Students

Brain Booster

On the International Space Station, an entire closed-loop system is dedicated to water recycling. In fact, 93 percent of the water on station is recycled from astronaut urine, sweat, respiration, and leftover wastewater from hygiene. Gateway will use similar technology for wastewater recycling while orbiting the Moon.

Learn more:
https://www.youtube.com/watch?v=BCjH3k5gODI&feature=youtu.be

On Location

The scientists and technical experts at Johnson Space Center's Toxicology and Environmental Chemistry laboratory play a critical role in establishing safe environmental limits for spacecraft. The team monitors air and water quality aboard current spacecraft and supports technology advancements for future space missions, including research for a next-generation trash bag to contain waste and nasty odors (like vomit) during long-duration missions!

Learn more:
https://www.youtube.com/watch?time_continue=430&v=TDtBT5XL5KQ

Activity Three: Experiment With Water Filtration

Student Handout

Your Challenge

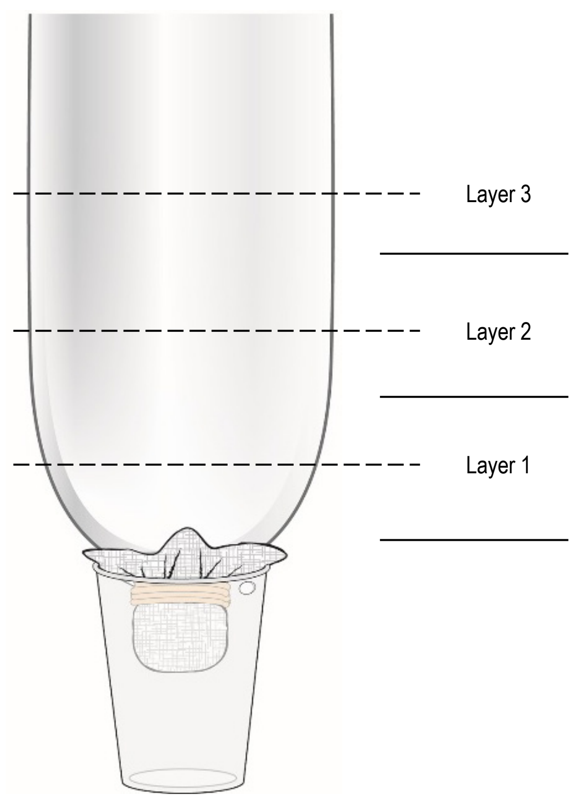
Create a water filtration system using an assortment of materials that will produce filtered water with a pH level of 6.5 to 8.5.

Ask and Imagine

- Why would water filtration devices be crucial to future deep space exploration missions?
- How is water filtered for use on Earth? Where do you get your drinking water?
- Where is potable (safe for drinking) water a problem on Earth?
- Think about the types of materials you will use and the order of placement in your water filtration system.

Plan

1. Choose three types of materials to use for your filtration layers.
   – Each material must be layered to a depth of 5 to 8 cm within your water filtration system.
2. On your own paper, create a sketch of your design like the example below.
   – On your sketch, draw each of the layering materials you have chosen for your filtration system.
   – Remember to label your sketch.
3. Next to your sketch, write your plan for layering your materials within your filtration system. How will your layers interact?

Sketch	Plan
	

Create and Test

1. Assemble your water filtration device.
   - Add your chosen layering materials to the bottle.
   - Set the bottle upside down on one of the four plastic cups. You will use a new cup for each trial.
2. Create a data table on your paper like the example below.
3. Prior to each trial, record your hypothesis (your prediction of what will occur). You will run a control trial followed by three experimental or test trials.
4. Test your water filtration device.
   - Pour the water into the top of the device and let it drip through the layering materials into the plastic cup.
   - Use a litmus paper strip to test the pH of the water in the paper cup. Use the pH color chart to determine the pH level.
5. Record your observations and the final results, including the pH level.

	Hypothesis	Observations	Results
Control Trial Clean water, 200 mL			
Test Trial 1 Gray water, 200 mL			
Test Trial 2 Gray water, 200 mL			
Test Trial 3 Gray water, 200 mL			

Share

- What was the greatest challenge for your team today? How did you address this challenge?
- How did the function of your water filtration device change throughout the trials?
- Which filtration material do you think worked best? Why?
- If you were to create another water filtration device, what would you do differently?
- If your device was used in space instead of on Earth, what would you have to modify? Why?

Fun Fact

The International Space Station's Water Recovery System is designed to recycle crew member urine and wastewater for reuse as clean water. This system reduces the net mass of water and consumables that would need to be launched from Earth to support six crew members by 2,760 kg (6,000 lb) per year!

Learn more: https://www.nasa.gov/stemonstrations-water-filtration.html

Career Corner

Food for Space Flight! Foods flown on NASA space missions are researched and developed by the Space Food Systems group. Food scientists, dietitians, and engineers ensure food is analyzed for use during space missions through nutritional analysis, sensory evaluation, freeze drying, rehydration, storage studies, packaging evaluations, and many other methods.

Learn more: https://www.nasa.gov/content/space-food-systems

Activity Four: Test Materials for a Radiation Shield

Educator Notes

Challenge

Students will use UV-sensitive beads to test a variety of materials to determine if they are suitable for shielding against ultraviolet (UV) radiation.

Suggested Time

45 to 60 minutes

Learning Objectives

Students will

- Discuss how Earth's atmosphere and magnetic field protect us from some harmful solar and galactic cosmic radiation.
- Test various materials for their ability to shield against UV radiation.

Curriculum Connection

Science and Engineering (NGSS)	
Disciplinary Core Ideas • MS-PS4-2 Waves and their Applications in Technologies and Information Transfer: Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. – PS4.B: Electromagnetic Radiation: When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends. A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media. However, because light can travel through space, it cannot be a matter wave, like sound or water waves. *Crosscutting Concepts* • Structure and Function: The way an object is shaped or structured determines many of its properties and functions. • Cause and Effect: Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.	*Science and Engineering Practices* • Engaging in Argument From Evidence: Argumentation is the process by which explanations and solutions are reached. • Analyzing and Interpreting Data: Scientific investigations produce data that must be analyzed in order to derive meaning. Because data patterns and trends are not always obvious, scientists use a range of tools—including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data. Scientists identify sources of error in the investigations and calculate the degree of certainty in the results. Modern technology makes the collection of large data sets much easier, providing secondary sources for analysis. • Planning and Carrying Out Investigations: Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters.
Technology (ISTE)	
Standards for Students • Knowledge Constructor: Students critically curate a variety of resources using digital tools to construct knowledge, produce creative artifacts, and make meaningful learning experiences for themselves and others. – 3d: Students build knowledge by actively exploring real-world issues and problems, developing ideas and theories, and pursuing answers and solutions.	*Standards for Students (continued)* • Innovative Designer: Students use a variety of technologies within a design process to identify and solve problems by creating new, useful, or imaginative solutions. – 4d: Students exhibit a tolerance for ambiguity, perseverance, and the capacity to work with open-ended problems.
Mathematics (CCSS)	
Mathematical Practices • CCSS.MATH.PRACTICE.MP3: Construct viable arguments and critique the reasoning of others.	*Mathematical Practices (continued)* • CCSS.MATH.PRACTICE.MP5: Use appropriate tools strategically.

Preparation Time

15 to 30 minutes

- Read the Introduction and Background, Educator Notes, and Student Handout to familiarize yourself with the activity.
- Print copies of the Student Handout.
- Gather and prepare all supplies listed on the materials list.
- Set up separate stations for each of the materials to be tested. The following materials will be tested to determine if they can shield against UV light:

- **Window glass**. This test must be done first. Students will place the UV beads against the window of the classroom to test whether the glass can shield against UV light. Once they verify that the windows and building provide sufficient shielding, they can proceed to test the other materials using the sunlight outside or a portable UV light source.
- **Metal can**. Students will place the UV beads in the palm of their hand or on a hard surface (such as a book) and cover the beads completely with the metal can.
- **Cotton fabric**. Students will wrap or cover the UV beads with a single layer of cotton fabric (such as a T-shirt).
- **Water**. Students will place the UV beads inside a clear plastic cup filled with water.
- **Clear plastic cup**. Students will place the UV beads in the palm of their hand or on a hard surface and cover the beads completely with the clear plastic cup.
- **Opaque plastic cup**. Students will place the UV beads in the palm of their hand or on a hard surface and cover them completely with the opaque plastic cup.
- **Foam cup**. Students will place the UV beads in the palm of their hand or on a hard surface and cover them completely with the foam cup.
- **Orange plastic pill bottle**. Students will place the UV beads inside the pill bottle and seal the lid.
- **Sunglasses**. Students will place the UV beads in the palm of their hand and cover them completely with a lens from a pair of sunglasses to test if the lens can shield against UV light. This test may work better if done in pairs, as it can be a challenge to keep light from penetrating gaps between the lens and the students' hands.
- **Paper envelope**. Students will place UV beads inside a paper envelope and seal it.
- **Sunscreen**. Students will place the UV beads inside a container that successfully shields UV light (such as a foam cup) and cover it with plastic wrap. Students will secure the plastic wrap in place with a rubberband and coat the exterior of the plastic wrap with sunscreen before they expose the cup to sunlight.

* Prepare the initial demonstration.
  - Use sunscreen to completely coat the outside of one or more sandwich bags, leaving one control bag with no sunscreen. When placed in the sunlight, the UV beads in the bag(s) protected by sunscreen will not turn as dark as the beads in the control (unprotected) bag. The darkness level of the beads will be affected by the sun protection factor (SPF) level of the sunscreen used, as seen in the image below.
  - Make sure to test the demonstration ahead of time.

Ultraviolent (UV) beads after exposure.

Share With Students

Brain Booster

Astronauts traveling into deep space will no longer be protected by the Earth's atmosphere and magnetosphere. They will be exposed not only to UV rays, but also to space radiation. Current spacecraft materials cannot block all of the radiation, so astronauts in space are exposed to more than the average person on Earth. For longer missions away from low Earth orbit, more protection from space radiation will be needed. NASA is already working on how to make the spacecraft safer by using different materials to provide protection.

Learn more:
https://www.nasa.gov/topics/moon-to-mars/preparing-to-go

On Location

NASA has teamed with the U.S. Department of Energy (DOE) Office of Science to establish the NASA Space Radiation Laboratory (NSRL) at the DOE's Brookhaven National Laboratory. NSRL scientists use beams of ions to simulate cosmic rays and assess the risks of space radiation to human space travelers and equipment.

Learn more:
https://www.nasa.gov/analogs/nsrl

***Note**: UV-sensitive beads can be purchased through several online retailers. Be sure to read the instructions, as brands may vary in color, how quickly they change colors, and how quickly they turn back to white.*

Materials

Per Student or Team

- ☐ 5 or 6 UV-sensitive beads
- ☐ Copy of Student Handout and blank paper
- ☐ Pipe cleaners or ribbon for making bracelets, key chains, or zipper pulls (optional)

Per Class

- ☐ Metal can (soup can)
- ☐ Cotton fabric (T-shirt)
- ☐ Water
- ☐ 2 clear plastic cups
- ☐ Opaque plastic cup
- ☐ 2 foam cups
- ☐ Orange plastic pill bottle
- ☐ Sunglasses
- ☐ Paper envelope
- ☐ Sunscreen
- ☐ Plastic wrap
- ☐ 2 or more plastic sandwich bags
- ☐ Rubberbands
- ☐ Optional: UV light source (blacklight) if access to sunlight is not available

Safety

- UV-sensitive beads present a choking hazard to children under the age of 3.
- If recycling used orange pill bottles, make sure they have been cleaned and any labels showing contents or personal information have been removed.
- If using a UV light source such as a blacklight, use eye protection and avoid direct contact with skin for prolonged periods of time.

Introduce the Challenge

- Show the class the two (or more) sandwich bags you prepared earlier. Do not tell them that any of the bags have been treated with sunscreen. Fill the bags with UV-sensitive beads. They should look identical before exposure to sunlight. Explain what happens to UV beads when they are exposed to UV light from the Sun or a blacklight. Take the class outside to observe what happens to the different bags of beads. Watch as the beads in the control bag become significantly darker than the beads protected by sunscreen. Challenge students to explain why this happens. Do not share the answer if the class has not yet figured it out.
- Return to the classroom and explain that the purpose of the investigation is to test a variety of materials to determine if those materials are suitable for shielding against UV radiation.
- Provide each student or team with five or six UV-sensitive beads, a copy of the Student Handout, and blank paper.
- If needed, the activity can be shortened by assigning each student or team only a few materials to test. Their findings can then be shared during a group discussion.

Facilitate the Challenge

Ask, Imagine, and Plan

- Provide context for this activity using the Introduction and Background information in this guide, focusing on the New Challenges Ahead: Radiation Shielding section.
- Engage students with the following discussion questions:
  - As astronauts venture beyond low Earth orbit and the protection of Earth's atmosphere and magnetosphere, what dangers will they face due to increased exposure to radiation?
  - What types of materials do you think will best protect against UV radiation? Why?

Test

- Demonstrate the procedure for testing materials. The beads should be completely covered with the testing material before students take them outside into the sunlight, and they should not be uncovered again until students return inside. A false positive can occur if sunlight penetrates gaps around the material or the beads are accidentally exposed.
- Students will test the UV beads with each material in the sunlight for about 10 seconds.
- Because it can take a few minutes for the beads to completely return to the white color after exposure, students or teams may pair up and share beads within the group to save time.
- Assist students or groups that are having problems and answer any questions as they move through each station.
- Allow the groups to bounce around to available stations to prevent long lines.
- Optional: Allow students to keep all or some of the UV beads to encourage continued awareness of UV radiation. Consider supplying pipe cleaners or ribbons to make bracelets, key chains, or zipper pulls. Students can even thread the beads onto their shoelaces.

Share

- After the investigation is complete, ask students again why one bag of beads in the class demonstration was darker than the other. If necessary, use guiding questions to allow the class to discover the difference between the bags. Identify the experimental bag(s) coated in sunscreen versus the control bag left unprotected.
  - Why did the beads in the bag(s) coated in sunscreen still change color?
  - Is it important to wear sunscreen when in the water? Why or why not?
  - What are other effective ways to protect your skin from harmful UV radiation?
- Engage students with the following discussion questions:
  - Why is it important for sunglass lenses to have UV protection? Discuss the results from the sunglass lens test.
  - Why is it important for medicine need to be protected from UV radiation? Discuss the results from the orange pill bottle test.
  - Did any of the results surprise you? Why?
  - Which materials might make good shielding for the walls of a space habitat?
  - Which materials might make good windows for a space habitat?
  - What other materials would you like to try in this experiment?

Extensions

- Expand the investigation to include different types of sunglasses (e.g., with and without polarizing filters) or different types of sunscreen (SPF, brand, and mineral-based).
- Find other materials that are semitransparent to visible light but block UV light (as sunglasses do).
- Find materials that block visible light (opaque) but allow UV light to pass through (some camera filters and “tan-through” fabrics).
- Research materials NASA is investigating for radiation shielding in space and identify the pros and cons of various solutions.

Reference

Modified from Exploring Ultraviolet (UV) Light From the Sun: https://sunearthday.nasa.gov/2007/materials/UVdetector.pdf

Additional Resource

- Digital Badging: Online NASA STEM Learning. https://www.txstate-epdc.net/digital-badging/

Activity Four: Test Materials for a Radiation Shield

Student Handout

Your Challenge

Use UV-sensitive beads to test a variety of materials and determine if they are suitable for shielding against ultraviolet (UV) radiation.

Ask, Imagine, and Plan

- During the demonstration, why did the beads in one bag become much darker than the beads in the other bag?
- As astronauts venture beyond low Earth orbit and the protection of Earth's atmosphere and magnetosphere, what dangers will they face due to increased exposure to radiation?
- What types of materials do you think will best protect against UV radiation? Why?
- On your own paper, create a data table like the example below, adding a new row for each material tested. Record your hypothesis or prediction in your data table before testing any material.

Test

Perform tests on the materials at each station and fill in the results, making notes about any observations on your data table.

Material (List each test material in a new row)	Hypothesis (Do you think the beads will be white, faintly colored, or dark colored?)	Results (White, faintly colored, or dark colored)	Does this material make a good shield against UV light? Why or why not?	Notes
Window glass				

Share

- Did any of the results surprise you? Why?
- Which materials might make good shielding for the walls of a space habitat?
- Which materials might make good windows for a space habitat?
- What other materials would you like to try in this experiment?

Fun Fact

Radiation isn't all bad! It is an essential tool for sterilization. One method of preserving fresh or packaged food is to expose it to ionizing radiation, which is a process known as cold pasteurization. This process kills any microbes that could cause spoilage or disease. UV radiation is also used to sterilize surfaces to ensure clean working conditions.

Learn more: https://www.fda.gov/food/buy-store-serve-safe-food/food-irradiation-what-you-need-know

Career Corner

Radiobiology is an interdisciplinary science that examines the biological effects of radiation on living systems. Radiobiologists incorporate fundamentals of biology, physics, astrophysics, planetary science, and engineering in their research to better understand the relationship between radiation and biology and to solve problems in this field.

Learn more: https://www.nasa.gov/hrp/elements/radiation/miniseries

Appendix: STEM Standards and Practices

Next Generation Science Standards (NGSS)

https://www.nextgenscience.org/

Alignment of Activities With NGSS Disciplinary Core Ideas				
Motion and Stability (MS) Standard	**Assess the Structural Integrity of a Space Module**	**Design and Build a Space Habitat**	**Experiment With Water Filtration**	**Test Materials for Radiation Shielding**
Forces and Interactions				
MS-PS2-1		✓		
Waves and Their Applications in Technologies and Information Transfer				
MS-PS4-2				✓
Engineering Design				
MS-ETS1-1	✓	✓		
MS-ETS1-2			✓	
MS-ETS1-3	✓	✓		
MS-ETS1-4			✓	
Ecosystems: Interactions, Energy, and Dynamics				
MS-LS2-1			✓	
MS-LS2-5			✓	

Alignment of Activities With NGSS Crosscutting Concepts				
Concept	**Assess the Structural Integrity of a Space Module**	**Design and Build a Space Habitat**	**Experiment With Water Filtration**	**Test Materials for Radiation Shielding**
Patterns				
Cause and Effect	✓	✓	✓	✓
Scale, Proportion, and Quantity				
System and System Models	✓	✓		
Energy and Matter				
Structure and Function				✓
Stability and Change			✓	
Interdependence of Science, Engineering, and Technology	✓	✓		
Influence of Engineering, Technology, and Science on Society and the Natural World			✓	

NGSS Science and Engineering Practices

https://ngss.nsta.org/PracticesFull.aspx

Alignment of Activities With NGSS Science and Engineering Practices				
Practice	**Assess the Structural Integrity of a Space Module**	**Design and Build a Space Habitat**	**Experiment With Water Filtration**	**Test Materials for Radiation Shielding**
Asking Questions and Defining Problems	✓	✓		
Developing and Using Models	✓	✓	✓	
Planning and Carrying Out Investigations	✓	✓		✓
Analyzing and Interpreting Data			✓	✓
Using Mathematics and Computational Thinking				
Constructing Explanations and Designing Solutions	✓			
Engaging in Argument From Evidence			✓	✓
Obtaining, Evaluating, and Communicating Information				

International Society for Technology in Education (ISTE) Standards for Students

https://www.iste.org/standards/for-students

Alignment of Activities With ISTE Standards for Students				
Standard	**Assess the Structural Integrity of a Space Module**	**Design and Build a Space Habitat**	**Experiment With Water Filtration**	**Test Materials for Radiation Shielding**
Knowledge Constructor				
3d			✓	✓
Innovative Designer				
4a	✓	✓		
4c		✓		
4d	✓	✓		✓
Computational Thinker				
5c	✓	✓	✓	
Global Collaborator				
7c	✓	✓	✓	

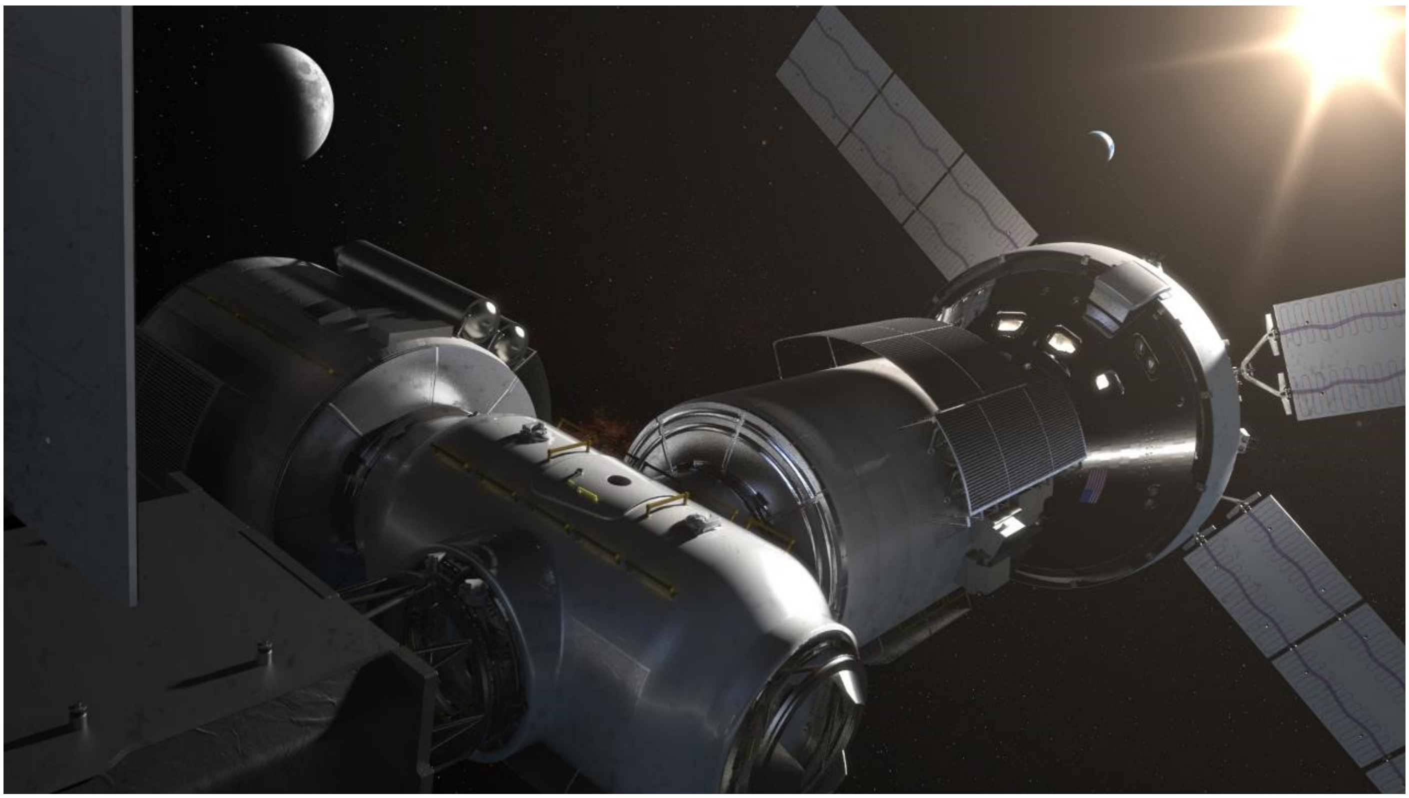
Common Core State Standards (CCSS) for Mathematics

http://www.corestandards.org/Math/

Alignment of Activities With CCSS Grade Level Content Standards by Domain				
Standard	**Assess the Structural Integrity of a Space Module**	**Design and Build a Space Habitat**	**Experiment With Water Filtration**	**Test Materials for Radiation Shielding**
6th Grade				
CCSS.MATH.CONTENT.6.NS.B.3	✓			
CCSS.MATH.CONTENT.6.SP.B.5	✓	✓	✓	
7th Grade				
CCSS.MATH.CONTENT.7.G.B.6		✓		
8th Grade				

Alignment of Activities With CCSS Standards for Mathematical Practice				
Practice	**Assess the Structural Integrity of a Space Module**	**Design and Build a Space Habitat**	**Experiment With Water Filtration**	**Test Materials for Radiation Shielding**
CCSS.MATH.PRACTICE.MP1	✓	✓		
CCSS.MATH.PRACTICE.MP2			✓	
CCSS.MATH.PRACTICE.MP3	✓	✓	✓	✓
CCSS.MATH.PRACTICE.MP4				
CCSS.MATH.PRACTICE.MP5	✓	✓	✓	✓
CCSS.MATH.PRACTICE.MP6	✓	✓	✓	
CCSS.MATH.PRACTICE.MP7				
CCSS.MATH.PRACTICE.MP8				

Back cover: As NASA sets its sights on returning to the Moon and preparing for Mars, it is laying the foundation for human exploration deeper into the solar system by creating an orbital outpost near the Moon called the Gateway. (NASA)



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

www.nasa.gov

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