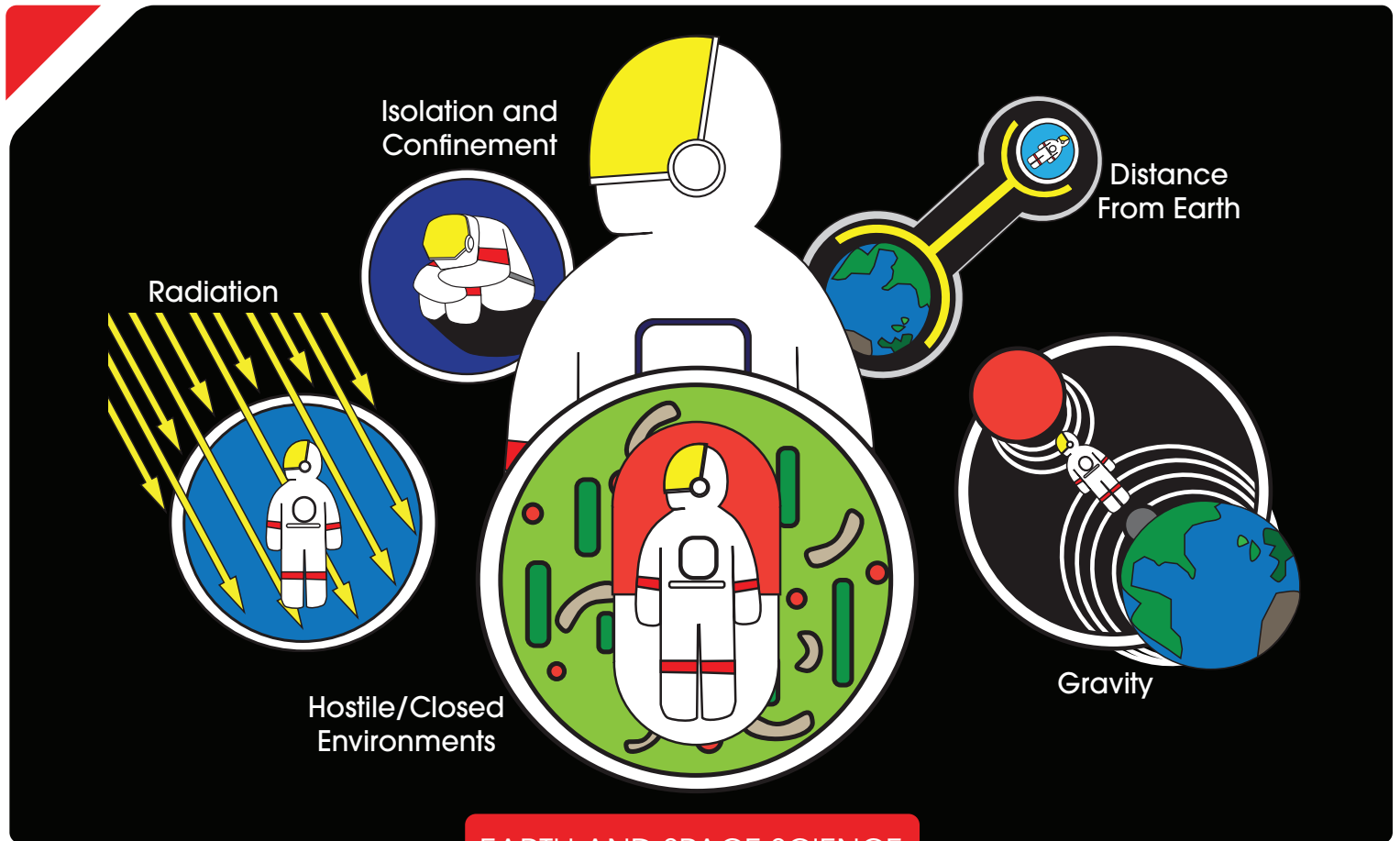


# Hazards to Deep Space Astronauts

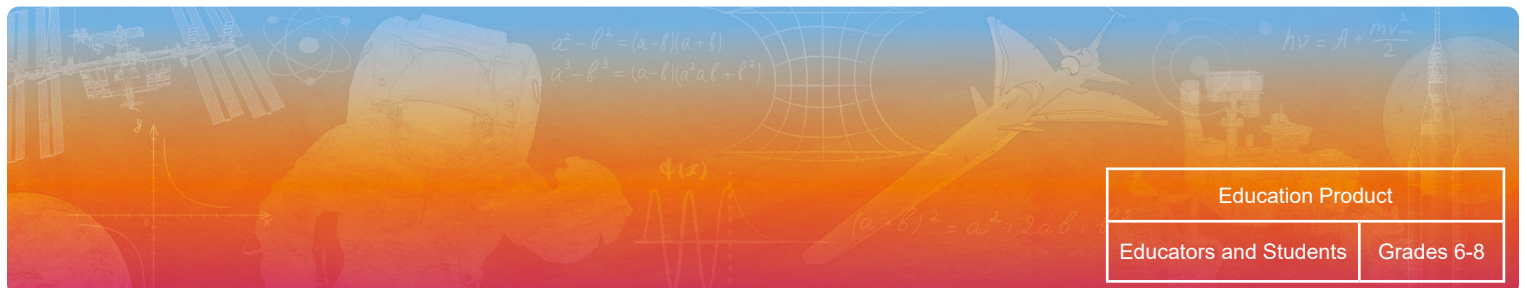
## Educator Guide



EARTH AND SPACE SCIENCE

## Next Gen STEM – Moon to Mars

For more about Next Gen STEM visit [https://www.nasa.gov/stem/nextgenstem/moon\\_to\\_mars](https://www.nasa.gov/stem/nextgenstem/moon_to_mars)



Education Product	
Educators and Students	Grades 6-8



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## Preface

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

## STEM Education Standards

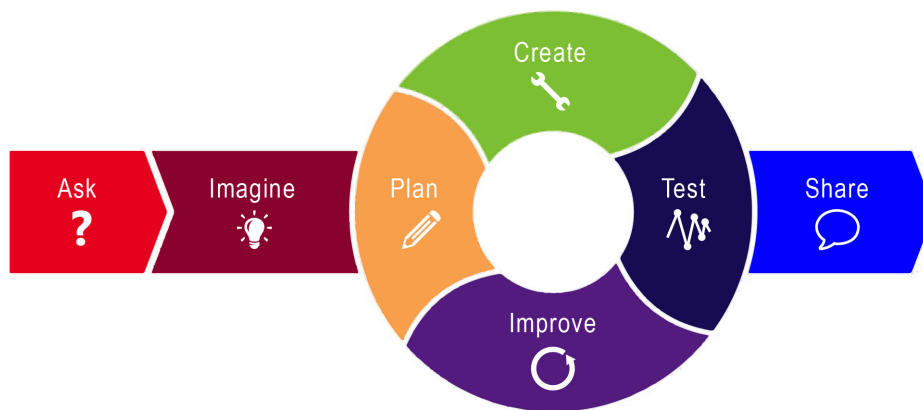
The STEM disciplines matrix shown below aligns each activity in this module to standards for teaching STEM according to four primary focus areas within each discipline. The four focus areas for science were adapted from the [Next Generation Science Standards](#) (NGSS) middle school disciplinary core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

Activity	STEM Disciplines															
	Science				Technology				Engineering				Math			
	NGSS Disciplinary Core Ideas				ISTE Standards for Students				NSTA and NGSS Practices				CCSS Content Standards by Domain			
	Physical Sciences	Life Sciences	Earth and Space Sciences	Engineering, Technology, and the Application of Sciences	Knowledge Constructor	Innovative Designer	Computational Thinker	Global Collaborator	Ask Questions and Define Problems	Develop and Use Models	Plan and Carry Out Investigations	Construct Explanations and Design Solutions	Ratios and Proportional Relationships	The Number System	Expressions and Equations	Ratios and Proportional Relationships
Radiation	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	
Isolation		✓	✓	✓		✓	✓	✓	✓		✓					
Distance			✓	✓			✓		✓	✓		✓	✓	✓	✓	✓
Gravity	✓	✓	✓	✓		✓		✓	✓		✓		✓	✓		
Environment		✓	✓	✓	✓				✓	✓	✓	✓	✓			✓

# Engineering Design Process

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

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



# Problem-Based Learning Process

In the problem-based learning process, the roles and responsibilities of educators and learners are different than in a traditional classroom setting. The educator acts as a facilitator by providing students with problems to work, assisting them in identifying and accessing the materials or equipment to solve the problems, giving necessary feedback and support, and evaluating students' participation. Learn more about the problem-based learning process at [www.cal.org/adultesl/pdfs/problem-based-learning-and-adult-english-language-learners.pdf](http://www.cal.org/adultesl/pdfs/problem-based-learning-and-adult-english-language-learners.pdf).

1. **Meet the Problem:** Identify the problem, introduce new vocabulary, and discuss previous experiences with the problem.
2. **Explore Knowns and Unknowns:** Use resources to explore the knowns and unknowns.
3. **Generate Possible Solutions:** Brainstorm possible solutions based on resources and prior experience with the problem.
4. **Consider Consequences:** Examine the pros and cons of each solution to determine a viable solution.
5. **Present Findings:** Communicate and discuss the process and solutions as a team.



## Teamwork

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

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

## Curriculum Connection

In this module, students will assume the role of researchers in NASA's Human Research Program as they study the dangers of deep space exploration. They will learn about the effects these hazards can have on the human body and what can be done to mitigate those dangers. Students will gain an understanding of the following five hazards (RIDGE):

1. Radiation exposure from a variety of sources during spaceflight
2. Isolation and the effects of loneliness from being away from family and friends or stuck in close proximity with only a few other astronauts for months at a time
3. Distance from Earth and the logistical complications that causes
4. Gravity fields and the related dangers to the human body due to long durations of time spent in microgravity
5. Environments that are hostile (such as the Martian surface) or closed (such as the space vehicle)

This guide will challenge students to work collaboratively to develop and design projects to help reduce the effects these hazards will have on deep space astronauts. Each activity suggests a variety of additional resources such as videos, podcasts, articles, e-books, or extension activities. Facilitators and educators are encouraged to explore these additional resources, because research into deep space hazards is ongoing and the knowledge gained is often applicable to inventions meant for use on Earth, which NASA refers to as spinoff technologies. The OYO® DoubleFlex exercise device and Orbital Systems' Oas shower are two examples of NASA spinoff technologies that were developed based on current research into deep space hazards.

## Weightless "Weight" Lifting Builds Muscle on Earth

Everyone should exercise, but astronauts need to dedicate a lot of time to it. They do not have exposure to Earth's gravity, which would normally require their bones and muscles to work all day just to stand up. In zero gravity, the human body quickly loses significant muscle and bone mass, making a rigorous workout schedule crucial to long-term health. Exercise during spaceflight requires special resistance-based devices because traditional exercise machines do not work without Earth's gravity. OYO® Fitness founder Paul Francis worked with NASA to develop a resistive exercise device suitable for use on the International Space Station. That exercise device eventually became a NASA spinoff, the OYO® DoubleFlex exercise device, which uniquely applies resistance to both sides of a muscle group through one motion, improving the efficiency of workouts. The DoubleFlex is also very light and easy to move; the device itself weighs just 2 pounds, but it provides up to 25 pounds of resistance. [spinoff.nasa.gov/Spinoff2018/hm\\_4.html](https://spinoff.nasa.gov/Spinoff2018/hm_4.html)

## Hazards to Deep Space Astronauts



NASA astronaut Garrett Reisman using a resistive exercise device that led to the innovation of several lines of exercise devices for use on Earth.

## Space-Age Water Conservation

Orbital Systems' Oas shower is the world's first water-recirculating shower. It was inspired by a university's partnership with NASA and is enabled by a filter technology NASA helped fund with an eye toward improving astronaut life-support systems. Learn more: [spinoff.nasa.gov/page/space-age-water-conservation-nasa](https://spinoff.nasa.gov/page/space-age-water-conservation-nasa)



NASA's 2021 Spinoff brochure includes information on hundreds more NASA technologies that benefit life on Earth in the form of commercial products. <https://spinoff.nasa.gov/sites/default/files/2020-12/NASA%20Spinoff%202021%20Brochure.pdf>



## Introduction and Background

Sending astronauts to Mars is one of NASA's primary 21st-century goals. In preparation for this long-duration spaceflight, NASA has been studying the health effects the trip could have on astronauts. Using various research platforms, NASA is always learning more about the hazards of deep space exploration and how to mitigate those effects. The International Space Station and upcoming [Artemis](#) lunar missions might immediately come to mind, but NASA also conducts analog missions here on Earth that simulate what living elsewhere in the solar system might be like. One such example is [NASA Extreme Environment Mission Operations \(NEEMO\)](#), where astronauts, engineers, and scientists study how to live and work deep in the Atlantic Ocean. NASA's [Human Research Program \(HRP\)](#) has organized the hazards astronauts encounter into five classifications, which allows for an organized effort to understand and overcome the obstacles that stand in the way of a deep space mission. It is important to understand that the risks do not stand alone; they are interrelated, and one hazard may exacerbate the effects of another on the human body. The five areas of research create the acronym RIDGE:

1. R—Space radiation
2. I—Isolation and confinement
3. D—Distance from Earth
4. G—Gravity (or lack thereof)
5. E—Hostile/closed environments

While these five challenges make spaceflight dangerous, they also provide opportunities for NASA to better understand the human body and, ultimately, make spaceflight safer through technological innovations.

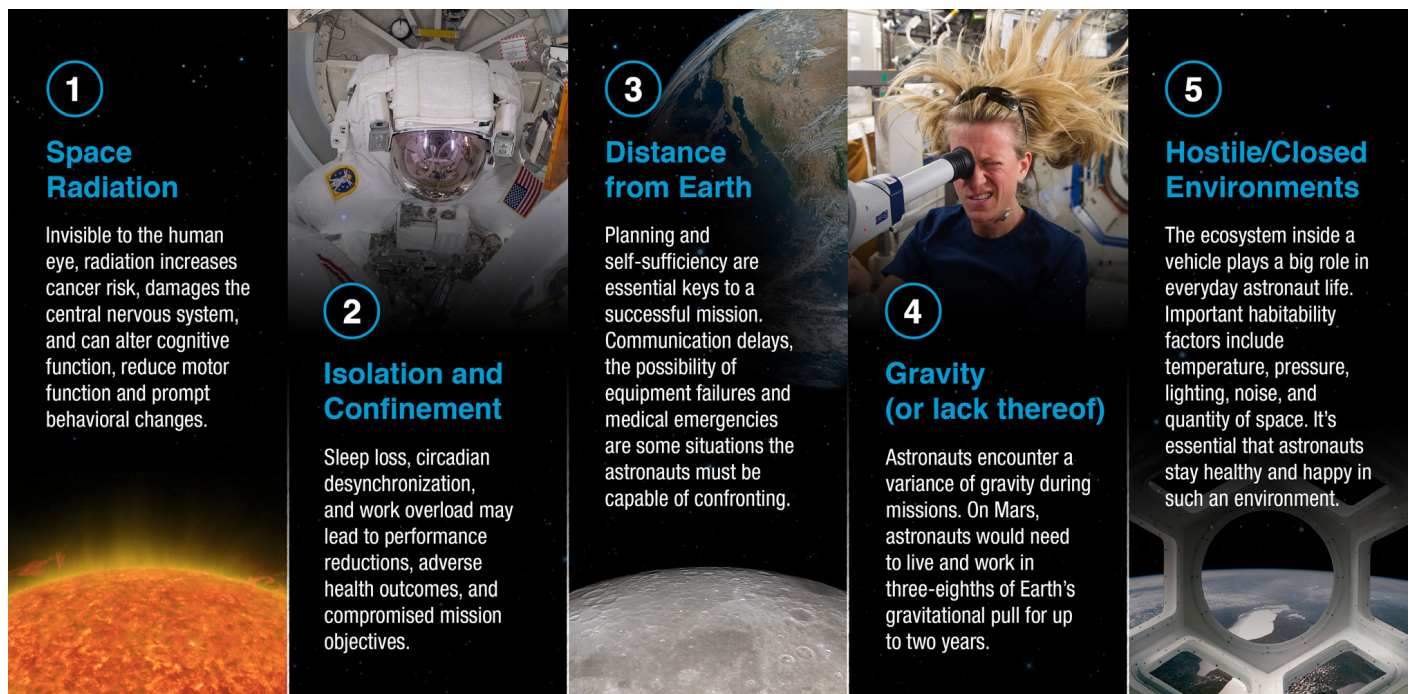


Illustration showing the top five hazards of human spaceflight. (NASA)

## RIDGE

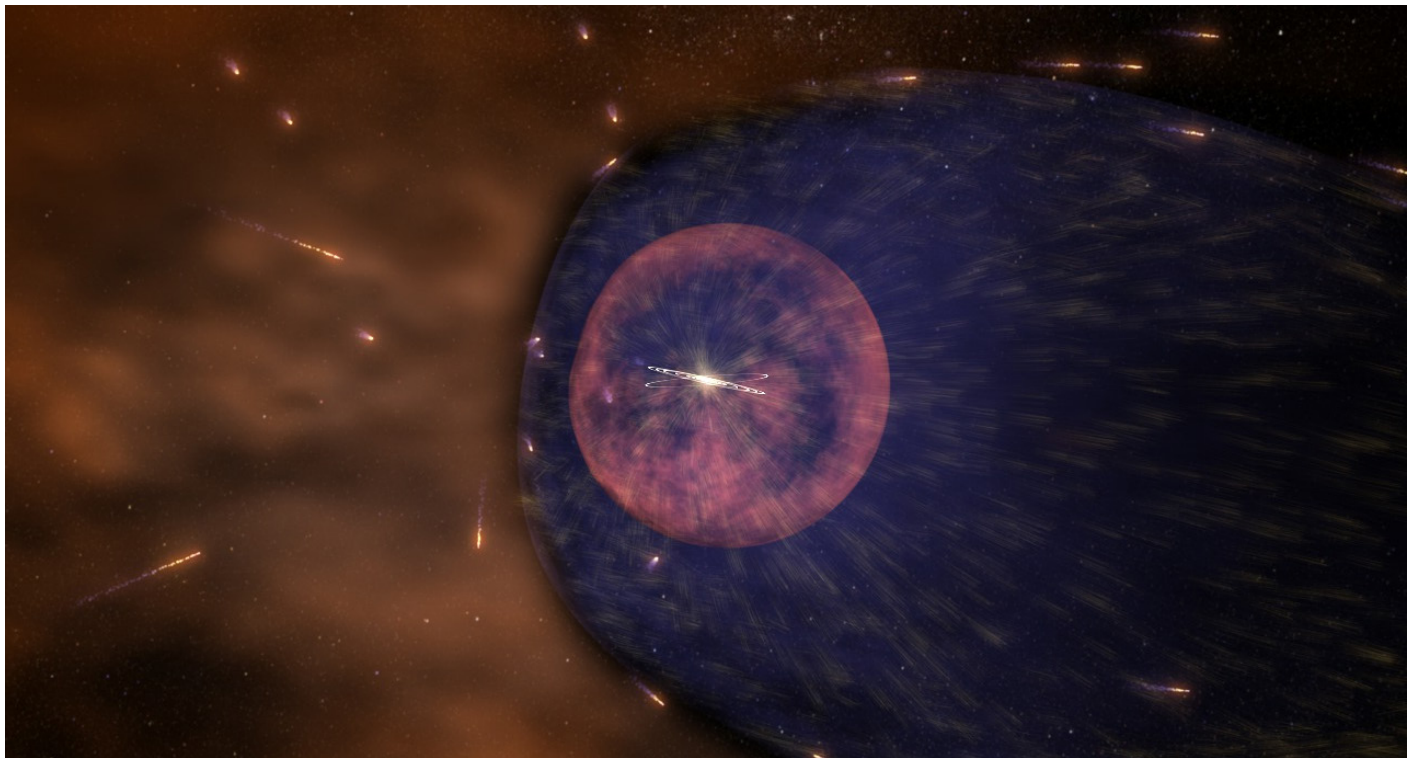
In this activity guide, students are given the opportunity to explore each of the top five hazards to crew during human spaceflight in order to frame an understanding of how each risk is dangerous on its own, and how the effects are compounded when multiple risks are present. Through problem-based learning activities or engineering design challenges, students are asked to assume the role of researchers in NASA's Human Research Program to help mitigate the risks faced by humans in long-duration spaceflights. The following content will give a better understanding of each of the hazards in the RIDGE acronym and what NASA is learning from research.

## Hazards to Deep Space Astronauts



Space is not empty. In fact, our solar system is full of high-energy particles that burst from the Sun and bombard us from the cosmos. On Earth, humans are relatively safe from this dangerous energy due to the magnetosphere, a protective “magnetic bubble” around the Earth that deflects most solar particles. This dangerous energy is called radiation, and it can have disastrous effects on electronics and the human body. The International Space Station travels through low-Earth orbit, within Earth’s protection, and the station’s metal hull helps to shield the

crew from harmful cosmic rays. Once an astronaut crew journeys beyond Earth’s protection, they face harsh radiation and must mitigate the harmful effects such exposure can cause. Two types of radiation are concerning to NASA in deep space: solar energetic particles (SEPs) and galactic cosmic radiation (GCR).



This [animated image](#) shows the solar system and the Sun’s magnetic bubble, called the heliosphere, that extends far beyond it. Bright streaks represent cosmic rays. During solar maximum, as the heliosphere strengthens, it blocks more cosmic rays. (NASA)

### Solar Energetic Particles (SEPs)

SEPs burst from the Sun in the wake of giant solar flares and coronal mass ejections. These particles are swept across the solar system and carried by the solar wind. Some of these SEPs can reach Earth, almost 93 million miles away, in less than an hour. SEPs are a type of energy that is either packaged in electromagnetic waves or carried by particles, like protons or ions. They are handed off when the wave or particle collides with something else, like an astronaut or spacecraft. SEPs are extremely dangerous because they can pass right through skin, shedding energy and fragmenting cells or deoxyribonucleic acid (DNA) along their way. This damage can increase risk for cancer later in life or—in extreme cases—can cause acute radiation sickness. Monitoring space weather is one way to help protect astronauts. Scientists alert mission control of potential solar events and may recommend that astronauts delay spacewalks or shelter in a heavily shielded area inside the space station until the event passes. During future Artemis missions, astronauts that are beyond Earth’s protective magnetosphere may be instructed to build a temporary shelter, making use of whatever mass is available, such as water bags or regolith (lunar soil). The more mass there is between the crew and the radiation, the more likely it is that the dangerous particles will deposit their energy before reaching the astronauts. The Orion spacecraft, which will carry crew members to the Moon during Artemis missions, uses a similar approach to protect astronauts. In addition to the built-in shielding provided by the capsule, radiation-sensing instruments will alert the crew when they need to take shelter using available materials in case of a radiation event. NASA and its partners are also testing wearable vests and devices that add a protective layer of mass to



protect the crew. Despite advances in space weather forecasting, the chaotic nature of SEPs makes it difficult to predict where they will go. We still have a lot to learn when it comes to protecting astronauts from space radiation.



Jessica Vos (foreground), deputy health and medical technical authority for Orion, and astronaut Anne McClain (background) demonstrate the radiation protection plan in a representative Orion spacecraft. During a solar energetic particle event, the crew will use stowage bags aboard Orion to create a dense shelter from radiation. (NASA)

### Galactic Cosmic Rays (GCRs)

The second kind of space radiation travels even farther than SEPs. GCRs are the remains of long-gone stars from elsewhere in the Milky Way, and they continuously bombard the solar system. Imagine that SEPs are like a sudden rain shower; GCRs, by contrast, are more like a steady drizzle. Cosmic rays tend to be much more powerful than SEPs. The same spacecraft that has been shielded to protect astronauts from SEPs cannot protect against the damage from GCRs, so they become a more serious concern, especially for long-duration missions like the journey to Mars. GCRs are composed of heavy elements like helium, oxygen, or iron. When these heavy particles collide with something, like an astronaut or the metal walls of a spacecraft, they knock atoms apart. This type of impact creates another problem: secondary radiation, in which a shower of more particles develops during the atomic collisions. This adds to the health concerns of cosmic rays. Cosmic ray exposure is also related to the solar cycle. During a solar minimum, when there is little solar activity, rays can infiltrate the Sun's magnetic field. During a solar maximum, the Sun's magnetic field strengthens, keeping some of the GCRs away.

Going to the Moon will help NASA collect crucial data for developing the necessary tools and strategies to safely send astronauts to Mars. The trip to Mars will take much longer than a trip to the Moon, and the crew will face much more radiation exposure. In Activity One of this module, students will have the opportunity to discover how much radiation astronauts will encounter and how that compares to a trip to the Moon or the International Space Station.



NASA astronauts have been flying to space for more than 50 years. For more than 20 of those years, crew members have been staying in space several months at a time on missions aboard the International Space Station, where they live with only a few other people in about as much space as a six-bedroom house. Astronauts experience various aspects of social isolation and confinement during their missions.

## Hazards to Deep Space Astronauts

NASA carefully selects crew members and trains and supports them to ensure they can work effectively as a team for as long as 1 year. NASA studies how isolation and confinement can alter astronauts' individual and team health and performance and also tests strategies to mitigate any negative impacts. These isolation studies are conducted with astronauts in space as well as in analog facilities such as the [Human Exploration Research Analog \(HERA\)](#), a Moscow facility called [Nezemyy Eksperimental'nyy Kompleks \(NEK\)](#), and field locations in Antarctica.

The space station orbits about 400 km (250 miles) above Earth. NASA is preparing for longer, more ambitious missions that will take astronauts farther away to the [Moon and Mars](#). Communication during human exploration missions to Mars will have to be innovative to account for the long delays caused by the much greater distance from the surface of the Earth. One of the lessons we have learned from life aboard the International Space Station is that it is important for crews and family members to manage expectations.

NASA has been studying people in isolated and confined environments for years and has developed methods and technologies to counteract possible problems. During space exploration, sleep restrictions and extended work hours can lead to fatigue. A 5-minute self-test helps astronauts objectively assess the effects of fatigue on performance. Journals give astronauts a safe place to write about their frustrations and give researchers a tool to study behavioral issues and thought processes of crew members who are living and working in isolation and confinement. All of these methods will help us prepare for longer, farther exploration missions.

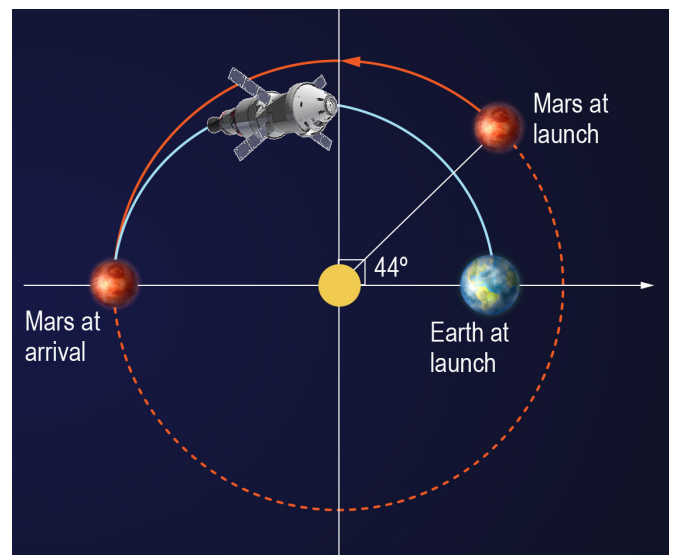
In Activity Two of this module, students will design a proposal to submit to NASA to mitigate the effects of isolation and confinement. Through research, including podcasts, students will become part of a company trying to sell its proposal to NASA.



One of the most apparent hazards to astronauts embarking on a deep space mission is the vast distance they will be from Earth. While a lunar voyage requires 3 days to travel about 384,000 km (239,000 miles) each way to the Moon, astronauts traveling to Mars will be away for as long as 3 years. The time it takes to travel from Earth to Mars varies depending on the positions of the two planets. Earth is approximately 150,000,000 km (93,205,678 miles) from the Sun and orbits every 365 days. Mars, however, is approximately 214,000,000 km (1,329,734,435 miles) from the Sun, and its orbital period is 687 days. Since Earth has a shorter orbital period, it is always “catching up” to Mars in their orbits around the Sun. Every 26 months, there is a window of time when a rocket can be launched from Earth on a trajectory that will have the spacecraft meet up with Mars in its orbit in the least amount of time. Even when taking advantage of these launch windows, a round-trip mission to Mars will take about 2 years.

NASA will send supplies ahead of crewed missions to the Martian surface in preparation for astronauts' stays on the Red Planet. In addition, supplies will be stationed in orbit to resupply their spacecraft for the voyage home. However, during the journey to Mars and back, the astronauts and their spacecraft must be completely self-sufficient. Once the spacecraft burns its engines, setting a course toward Mars, there is no way to turn back and no way to receive additional supplies until it reaches its destination. Also, due to the mass and volume of consumables such as water and air, there will not be space for supplies that are not absolutely essential.

To make the journey possible, the spacecraft will incorporate regenerative life support systems. These systems are responsible for recovering consumed air and water aboard a spacecraft and recycling them into breathable air and clean, drinkable water. Three of the critical systems, developed at NASA's Marshall Space Flight Center in Huntsville, Alabama, are the water recovery system, the air revitalization system, and the oxygen generation system. The water recovery system is continually being improved for increased efficiency and reliability. The current version of the system, which is in use aboard the International Space Station, can recover and recycle more than 90 percent of the wastewater aboard the space station and turn it back into clean water for the astronauts' use. With limited supplies and no support from their team back on





Earth, astronauts on a journey to Mars will need even more efficient and reliable systems in order to be self-sufficient, including a water resupply system that can recover 98 percent of the water.

In Activity Three of this module, students will calculate the water needs of astronauts on a deep space mission. Using research and their calculated water consumption rates, they will make determinations concerning a water efficiency problem on a deep space mission.



As astronauts travel to deep space, they will encounter three different gravity fields. The gravity they will experience on the Moon's surface is one-sixth of Earth's gravity. In transit from the Moon to Mars, they will be living in an environment that has zero gravity. During a Mars surface mission, they will be living and working in gravity that is three-eighths that of the Earth. Each time the gravity changes, there will be an effect on hand-eye coordination, locomotion, spatial orientation, balance, bones, muscle, and heart function. The way our bodies perform is related to how we react to gravity.

One main reason our bones and muscles are strong is that they must constantly work to fight the effects of Earth's gravity. In the absence of gravity, an astronaut's bone density decreases, which is why it is critical for astronauts to exercise during transit flight. If they do not, there can be serious atrophy of the bone and muscle. Bones weaken because astronauts are not applying stress, or weight load, on the back and leg muscles. This is similar to what happens with bedridden patients on Earth, whose muscles and bones weaken due to lack of movement. Bones are constantly being broken down and rebuilt as a person grows. However, people with osteoporosis have more bone loss than rebuilding. This loss may not hinder astronauts while they are in orbit, but upon returning to Earth, their weakened bones will be fragile and at increased risk for fractures. Additionally, the minerals that are lost from the bones may be displaced elsewhere in the body, causing astronauts to develop kidney stones. The rate of bone density loss in space is 1 percent per month. This is comparable to bone density loss in elderly men and women, whose rate of loss is 1 to 1.5 percent per year. This bone loss can cause astronauts to have osteoporosis-related fractures later in life. Bone loss is just one of the effects of decreased gravity on an astronaut.

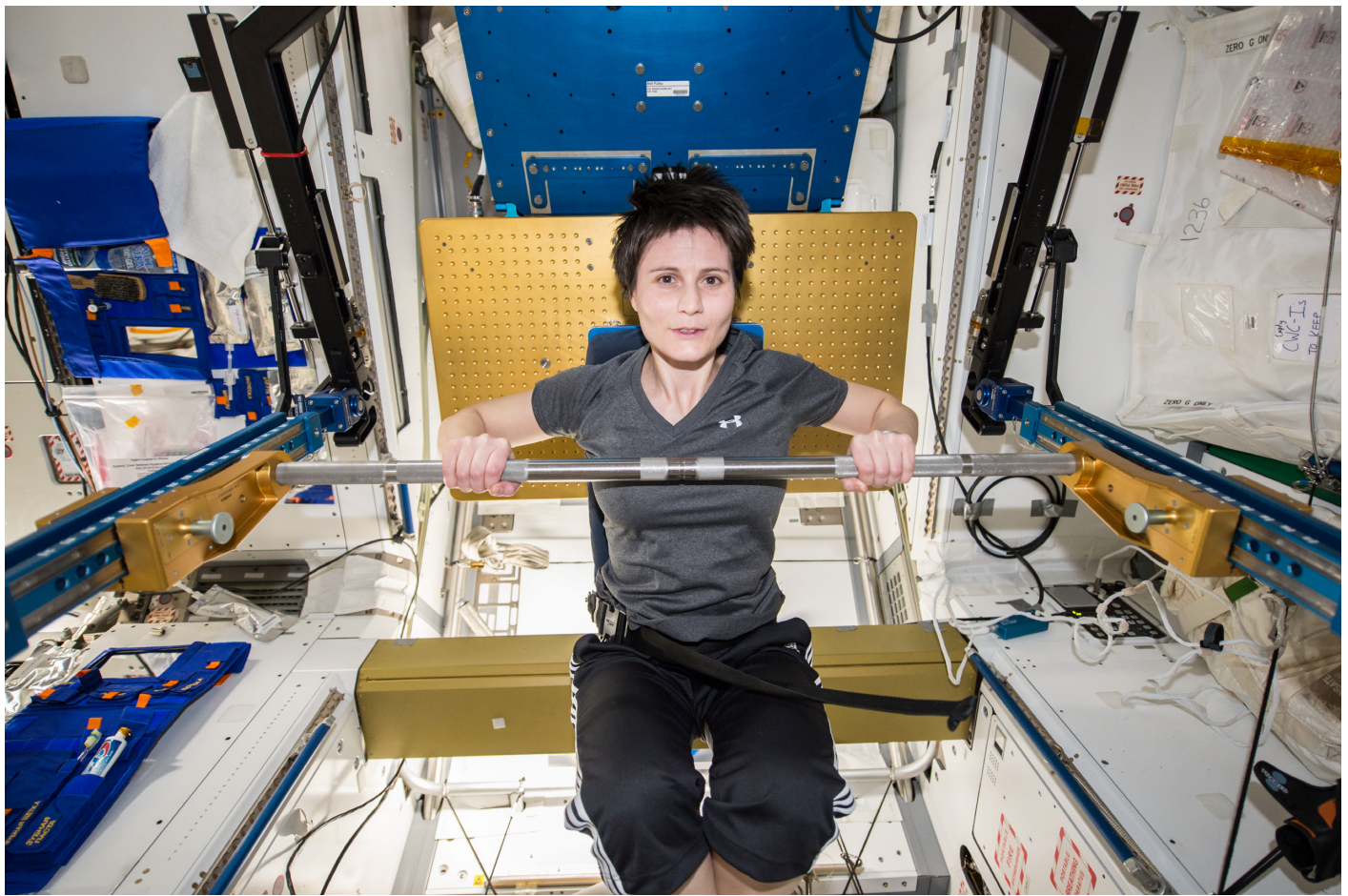
Fortunately, NASA scientists know that there are three countermeasures, or activities that can decrease the risks, for preventing bone loss: nutrition, exercise, and medicine. Meals are nutritionally balanced with calcium-rich foods and vitamin D. Physical exercise is important to increase bone load and muscle strength. Astronauts are also given bisphosphates, a therapeutic agent that has been used to treat osteoporosis patients, to increase bone mass and decrease the occurrence of bone fractures. Although the Moon and Mars do exert more gravitational force on the body than is experienced during spaceflight, they exert less force than Earth does. Therefore, even after landing on a celestial body, astronauts will still need lots of exercise to maintain muscle and bone mass that they would maintain just by being on Earth.

Another effect that scientists are closely monitoring is the fluid shift that takes place in the human body during spaceflight. On Earth, an astronaut's circulatory system is accustomed to working against gravity. During spaceflight, the circulatory system receives a different set of signals and stimuli. The heart does not need to work as hard to send blood to the upper body, which leads to an increase in the volume of blood shifting upward toward the head. This shift can put pressure on the eyes and cause vision loss. NASA scientists provide astronauts with compression cuffs to wear on their thighs, which helps keep blood in the lower extremities to counteract the fluid shift.

NASA scientists are still performing research to develop protocols for replacing the positive health effects of Earth's gravity on astronauts. This research will benefit not only astronauts in deep space but also people on Earth who experience loss of bone density and muscle mass.

In Activity Four of this module, students will design an exercise device that can operate in different gravity fields. Using their knowledge of the skeletal system, fracture threshold, and osteoporosis, the students' designs will mitigate the effects of bone loss and muscle atrophy.

## Hazards to Deep Space Astronauts



European Space Agency astronaut Samantha Cristoforetti exercises on the Advanced Resistive Exercise Device aboard the International Space Station. (NASA)



NASA has learned that the ecosystem inside the spacecraft plays a big role in everyday astronaut life in space. Microbes can change characteristics in space, and micro-organisms that naturally live on the human body are transferred more easily from person to person in closed habitats such as the space station. Stress hormone levels are elevated, and the immune system is altered, which could lead to increased susceptibility to allergies or other illnesses.

Earth-based analogs do not perfectly simulate the spaceflight environment, making them insufficient for studying on the ground how human immune systems react in space. However, NASA-funded Antarctic analog studies could provide insight into how certain spaceflight stressors may affect the human immune system. What is known is that spaceflight changes the immune system, although crews do not tend to get sick upon returning to Earth. Even though astronauts' acquired immunity is intact, more research is needed into whether spaceflight-induced altered immunity may lead to autoimmune issues, in which the immune system mistakenly attacks the healthy cells, organs, and tissues present in the body.

Astronauts are advised to get a flu shot to boost their immunity and are quarantined before their missions to avoid catching any sort of illness before launch. During his 1-year mission aboard the space station as part of the [NASA Twins Study](#), Scott Kelly administered a flu vaccine to himself while his brother received a vaccination on Earth. The immunization proved to work as well in space as it does on Earth, which is a good finding for longer missions to the Moon and Mars.

NASA is using technology to monitor the air quality of the space station to ensure the atmosphere is safe to breathe and not contaminated with gases such as formaldehyde, ammonia, and carbon monoxide. Thermal control systems function to maintain temperatures of the space station and keep astronauts comfortable. Blood and saliva samples are analyzed to identify changes in the immune system and the reactivation of latent viruses during spaceflight. NASA uses advanced molecular techniques to evaluate the risk of microbes that may cause illness for crew members. Various parts of the body and the space station are swabbed regularly

for analysis of the microbial population that inhabits the environment. Crews change out air filters, clean surfaces, and treat the water to prevent illnesses that may result from the accumulation of contaminants.

Beyond the effects of the environment on the immune system, every inch and detail of living and working quarters must be carefully thought out and designed. No one wants their house to be too hot, too cold, cramped, crowded, loud, or not well lit, and no one would enjoy working and living in such a habitat in space either. Living quarters and work environments are carefully planned and evaluated to ensure that designs balance comfort and efficiency. Lighting onboard the space station is similar to what would be experienced naturally on Earth, thanks to the light-emitting diode (LED) lighting system.

NASA is acting on all risks and working to solve the challenges of human spaceflight with some of the most brilliant minds in related fields. The results garnered from laboratories, ground analogs, and space station missions will continue to provide insight into these adaptations and present stepping-stones for longer missions. On upcoming missions to lunar orbit and the surface of the Moon, even more data will be collected as this work continues. On future longer-duration missions to the Moon and Mars, astronauts will benefit from years of research that will ensure they are able not just to survive, but to thrive.

In Activity Five of this module, students will compare and contrast the environment of the Earth, the Moon, and Mars. Students will then use this knowledge to design a habitat on one of the celestial bodies that will be able to renew or recycle elements to sustain life.

## Activity One: Radiation

### Educator Notes

#### Learning Objectives

Students will

- Identify everyday radiation exposures on Earth.
- Contrast Earth radiation exposures with those experienced by astronauts in deep space.
- Explain the effects of radiation exposure on the human body.
- Investigate the importance of radiation shielding for deep space travel.

#### Challenge Overview

Students will compare and contrast radiation exposure on Earth with radiation exposure in space. This activity culminates with a challenge in which students will need to protect a potato “astronaut” from the harmful effects of the radiation in their ovens.

#### Suggested Pacing

90 to 120 minutes

#### National STEM Standards

Science and Engineering (NGSS)	
<p><i>Disciplinary Core Ideas</i></p> <ul style="list-style-type: none"> <li>• MS-PS3-3: Energy: Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.</li> <li>• MS-LS3-1: Heredity: Inheritance and Variation of Traits: Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism.</li> <li>• 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.</li> </ul> <p><i>Crosscutting Concepts</i></p> <ul style="list-style-type: none"> <li>• Energy and Matter: The transfer of energy can be tracked as energy flows through a designed or natural system.</li> </ul>	<p><i>Crosscutting Concepts</i></p> <ul style="list-style-type: none"> <li>• Structure and Function: Complex and microscopic structures and systems can be visualized, modeled, and used to describe how their function depends on the shapes, composition, and relationships among its parts, therefore complex natural structures/systems can be analyzed to determine how they function.</li> </ul> <p><i>Science and Engineering Practices</i></p> <ul style="list-style-type: none"> <li>• Constructing Explanations and Designing Solutions: Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process, or system.</li> <li>• Developing and Using Models: Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.</li> <li>• Engaging in Argument From Evidence: Evaluate competing design solutions based on jointly developed and agreed-upon design criteria.</li> </ul>
Technology (ISTE)	
<p><i>Standards for Students</i></p> <ul style="list-style-type: none"> <li>• Knowledge Constructor: Students critically curate a variety of resources using digital tools to construct knowledge, produce creative artifacts, and make meaningful learning experiences for themselves and others.</li> <li>• Innovative Designer: Students use a variety of technologies within a design process to identify and solve problems by creating new useful, or imaginative solutions.</li> </ul>	<p><i>Standards for Students (continued)</i></p> <ul style="list-style-type: none"> <li>• Creative Communicator: Students communicate clearly and express themselves creatively for a variety of purposes using the platforms, tools, styles, formats, and digital media appropriate to their goals.</li> <li>• Global Collaborator: Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally.</li> </ul>
Mathematics (CCSS)	
<p><i>Mathematical Practices</i></p> <ul style="list-style-type: none"> <li>• MP.27.EE.3: Solve multistep real-life and mathematical problems posed with positive and negative rational numbers in any form (whole numbers, fractions, and decimals), using tools strategically. Apply properties of operations to calculate with numbers in any form, convert between forms as appropriate, and assess the reasonableness of answers using mental computation and estimation strategies.</li> </ul>	

#### Challenge Preparation

The educator should

- Read the introduction and background information, Educator Notes, Student Handout, and Radiation Exposure on Earth Worksheet to become familiar with the activity.
- Print copies of the Student Handout and the Radiation Exposure on Earth Worksheet for each student.
- Preheat oven or toaster oven.



## Materials

- Wooden block tower
- Potato (at least 2 per team)  
Note: Ensure potatoes are similar in mass. Educator may also use several different varieties of potatoes as an extension activity.
- Cookie sheet or another oven-safe pan
- Oven or toaster oven set to 350 °F
- Food thermometer or probe thermometer to test internal temperature of the potato
- Various oven-safe materials to protect potato (tin foil, parchment paper, clay, oven bags, salt, etc.)

### Safety

- Use potholders or oven mitts and wear protective eyewear when moving items in and out of the oven and when checking the temperature of the potato.
- Be sure to use oven-safe materials, including the oven mitt, sheet or pan, and materials wrapped around the potato.
- Do not place potato directly on oven rack, but instead use a cookie sheet or other type of oven-safe pan.
- Have a flat and heat-resistant surface ready to place the cookie sheet or pan on after removal from oven. Remove any clutter, other equipment, and all combustible materials from area.

## Introduce the Challenge

- Inform students that they will be learning about radiation and the effects of radiation exposure on astronauts in space.
- Explain to students that they will be working in teams to protect a potato “astronaut” from the harmful effects of radiation exposure in an oven. It is important to note and explain to students that the infrared radiation from an oven is different in wavelength and intensity than the radiation from solar energetic particles (SEPs) or galactic cosmic radiation (GCR) and that this activity is just an illustration of the effects of radiation.
- Ask students what they think astronauts and potatoes have in common.
- Review the following criteria and constraints of the activity with students:

Criteria	Constraints
After baking, the experimental potato must have a lower internal temperature than the control potato (the lower, the better).	You may not use more than three layers of protection on your “astronaut.”
All protective materials for the potato must be oven safe.	You may not use water or other liquids as protection for this activity.
The experimental and control potatoes must be cooked for the same amount of time at the same temperature.	

## Facilitate the Challenge

### Ask

- Begin this activity with a demonstration using a stacked tower of wooden blocks (e.g., a tumble tower). Explain to students that the game represents a strand of their DNA. Remove a block from anywhere on the structure and explain to students that when

## Share With Students



### Brain Booster

Bananas are a natural source of radioactive isotopes. A “banana equivalent dose (BED)” is a unit that compares radiation exposure to the amount you naturally get from eating a banana. 1 BED is equal to 0.001 millisievert (mSv).

A lethal dose of radiation would be comparable to the radiation you would get from eating 80 million bananas!

See more comparisons on the Student Handout.

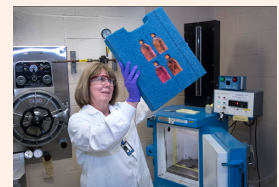
Learn more:

[www.nasa.gov/sites/default/files/files/Radiation\\_Math.pdf](http://www.nasa.gov/sites/default/files/files/Radiation_Math.pdf)



### On Location

The research performed at the NASA Space Radiation Laboratory (NSRL) at the Brookhaven National Laboratory in New York increases our understanding of ionizing radiation and cell damage. Researchers are working to limit the damage to healthy tissue by cosmic radiation, which will lead to safer exploration for astronauts and possible improvements in cancer-fighting treatments for everyone.



Learn more:

[www.bnl.gov/nsrl/](http://www.bnl.gov/nsrl/)

## Hazards to Deep Space Astronauts

someone is exposed to radiation, it destroys or changes a small part of that strand. Continue to pull out random blocks and ask for student observations. Explain that sometimes the tower tumbles with the removal of one block, but that other times several blocks need to be removed before the tower tumbles.

- Ask students what would happen if a marble was thrown at the stack of blocks instead of single blocks being carefully removed. Explain that a marble would represent what being exposed to galactic cosmic radiation (GCR) is like. GCR is much more damaging than exposure from solar energetic particles (SEPs) because GCR is high in atomic mass and has extremely high energy. For more information on DNA damage, read “Space Radiation is Risky Business for the Human Body” at [www.nasa.gov/feature/space-radiation-is-risky-business-for-the-human-body](http://www.nasa.gov/feature/space-radiation-is-risky-business-for-the-human-body). This website page also includes a video that can be shared with students.
- Explain to students that in this activity they will be learning how much radiation they are exposed to on a yearly basis on Earth and will be comparing this exposure rate to that of astronauts on the International Space Station, on a trip to the Moon, and even on a deep space exploration trip to Mars. Before students complete the Radiation Exposure on Earth Worksheet, hold a whole-group discussion about radiation exposure on Earth. How commonly do students think it occurs? What causes it?

Note: It may be helpful to complete the worksheet while the potato “astronauts” are baking in the oven.

- In the last part of this activity, students will work in small teams to create protective shielding for “potato” astronauts before baking them in an oven. Discuss with students the importance of shielding to protect astronauts from SEPs while they are in space, away from the protection of Earth’s magnetosphere. Putting as much mass as possible between the astronauts and SEPs will help shield the astronauts from harmful radiation.

### Imagine

- Hand out to each student a copy of the Radiation Exposure on Earth Worksheet.
- Students will work individually on the handout to determine the amount of their own personal exposure rates.
- As a large group, determine the exposure rates in Banana Equivalent Doses (BEDs) of astronauts on (1) the International Space Station, (2) a trip to the Moon, and (3) a trip to Mars.

### **Discussion Questions and Answer Key**

1. The average exposure for 1 year on Earth is about 3.0 mSv. How does your annual radiation dose compare to the average? How does your annual radiation dose compare to other students?
2. The average exposure rate for astronauts on the International Space Station for a 6-month stay is 160 mSv. What is the banana equivalent dose, or BED, for those astronauts? **Answer: 160,000**
3. The average radiation exposure for astronauts living on the Moon for 9 days is 11.4 mSv. What is the BED for those astronauts? **Answer: 11,400.** Why is this number less than the BED for a stay on the International Space Station? **Answer: Astronauts are on the International Space Station for 6 months, not 9 days.**
4. The estimated radiation exposure for astronauts on a 3-year round-trip mission to Mars is 1,200 mSv. What is the BED for a trip to Mars? **Answer: 1,200,000.** If a lethal dose of radiation is the equivalent of eating 80 million bananas, about how many trips to Mars could you make? **Answer: 8**

### Plan

- Place students in small teams of no more than four.
- Explain that students will need to brainstorm how they will protect a potato “astronaut” from the radiation of an oven.
- Make sure students understand what materials they have available to them and how much they are permitted to use.
- Teams should be given at least two potatoes. One will serve as a control, where no protection is given, and the other will be the experimental potato.

Note: At the discretion of the educator, teams can be given only one potato and the final temperature of a control potato can be given to the students beforehand. Students can also use more than one potato, or potatoes of different varieties, and protect

them in various ways. For example, they can compare the effectiveness of one layer of aluminum foil versus the effectiveness of three layers of aluminum foil.

### Create

- After students have brainstormed a solution to best protect their potato, they will wrap the potato “astronaut” using no more than three layers of material and ensuring the entire potato is covered, with no gaps or holes. Discuss how this protective “spacesuit” is similar to the lead apron that is worn during x-rays.
- If students are using more than one potato, each protective spacesuit should be made differently.

### Test

- Teams will bake their “astronaut” potatoes in an oven. To save time, preheat the oven. The control potato will have no protection and must be baked at 350 degrees for 30 minutes.

Note: Educator can vary time or temperature but must keep variables consistent for all potatoes. If an oven is not available, consider using the school cafeteria, or send potatoes home to be baked and tested.

- Teams will then bake their protected astronauts for 30 minutes at 350 degrees.  
Note: It may be helpful to have students work on the Radiation Exposure handout while the potatoes are baking.
- Teams will take the internal temperature of their control potato and their protected potato “astronauts.”
- Have students graph or create a table of their results to share with the rest of the teams.

### Improve

- Ask students if their spacesuit protected their astronauts. Did the internal temperature improve over the control potato’s temperature?
- If no improvement was made, allow teams to brainstorm and discuss what they would do to improve their designs. If time permits, allow teams to test their new designs and include any new data in their original graph or table.

### Share

Engage students with the following discussion questions:

- Compare your team’s results with the other teams’ results. How did your spacesuit compare to the others? What improvements could be made if you had the time?
- How is this activity similar to the development of protective spacesuits for astronauts?
- Compare and contrast between the radiation that real astronauts are exposed to in space and the radiation that your potato “astronauts” experienced.

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

### Extensions

- Create a price list for materials and give student teams a budget they must work within. For example, make aluminum foil more expensive than parchment paper to help students realize that engineering involves tradeoffs between price and performance.
- In your journal, write a reflection on what you have learned from this activity. Describe the importance of spacesuit and spacecraft materials in the mitigation of radiation exposure on a deep space journey.

### Reference

Space Faring: The Radiation Challenge (Middle School Educator Guide)

[www.nasa.gov/pdf/284277main\\_Radiation\\_MS.pdf](http://www.nasa.gov/pdf/284277main_Radiation_MS.pdf)

# Activity One: Radiation

## Student Handout

### Your Challenge

You will be comparing and contrasting radiation exposure on Earth with radiation exposure in space. This activity culminates with a challenge in which you will need to protect a potato “astronaut” from the harmful effects of the radiation of an oven.

Criteria	Constraints
After baking, the experimental potato must have a lower internal temperature than the control potato (the lower, the better).	You may not use more than three layers of protection on your “astronaut.”
All protective materials for the potato must be oven safe.	You may not use water or other liquids as protection for this activity.
The experimental and control potatoes must be cooked for the same amount of time at the same temperature.	

### ? Ask

- Your instructor will demonstrate the effects of radiation by using a stack of blocks to represent your DNA. DNA is located inside each of your cells and carries all the information about how you look and function. Removing a block from the stack demonstrates the effect that a small dose of radiation has on your DNA. What do you anticipate will happen as your instructor continues to remove blocks? What would happen if you threw a marble at the tower of blocks? That would be an illustration of another type of radiation that astronauts are exposed to in space: galactic cosmic radiation (GCR).

### 💡 Imagine

- In the next part of this activity, you will learn how much radiation you are exposed to on a yearly basis on Earth. Reflect and discuss with the whole group how you think radiation exposure occurs here on Earth. After this group discussion, you will receive a handout to complete and compare your data with other students.
- Next, you will compare your yearly exposure rate to that of astronauts who are (1) living on the International Space Station, (2) on a trip to the Moon, and (3) on a deep space exploration trip to Mars.

### ✏️ Plan

- In the last part of this activity, you will work in a small team to create protective shielding for a potato “astronaut” before baking it in an oven. This is to illustrate the radiation exposure astronauts would face in space. Understand that radiation from the oven is very different than the types of radiation encountered in space, but this is a good way to illustrate the importance of protection and shielding for astronauts.
- Use a sheet of paper to brainstorm how your team will use the materials provided to protect a potato “astronaut” from the radiation of an oven. Be descriptive, and be sure to label your drawings.

### Fun Fact

Did you know that there is a type of fungus that feeds on radiation to create chemical energy for growth? It’s true! Scientists have discovered a type of fungus at Chernobyl, the site of the world’s worst nuclear disaster. The fungus survives using a unique process called radiosynthesis that works like photosynthesis but uses the energy from radioactivity instead of sunlight. Scientists have recently discovered that the properties of this fungus could help protect people from radiation, like the astronauts on the International Space Station. The fungus could eventually be used to create a space-approved sunscreen!

Learn more:

[hub.jhu.edu/2019/11/01/melanin-space-study/](http://hub.jhu.edu/2019/11/01/melanin-space-study/)

### Career Corner

Scientists working with the Johnson Space Center’s Space Radiation Group (SRG) monitor the space weather forecast from the National Oceanic and Atmospheric Administration’s Space Weather Prediction Center. They alert mission control of potential solar activity and can recommend postponing activities that would require astronauts to perform spacewalks. Anywhere astronauts may go, SRG scientists will keep watch over the space environment. Interested in becoming a space meteorologist?

Learn more:

[ccmc.gsfc.nasa.gov/](http://ccmc.gsfc.nasa.gov/)



### Create

- After your team has brainstormed a solution to best protect your potato, use the materials you have chosen to carefully wrap your potato “astronaut.” Make sure the entire potato is covered, with no gaps or holes. This is your experimental potato.
- The second potato will be your control potato. It should be left completely unprotected. Ideally, your experimental potato will “survive” what the control potato could not. Whenever possible, good experiments have a control to make sure that the experiment did not just work, but worked better than doing nothing, because sometimes you can make things worse by accident.

### Test

- It is time to test your protective spacesuits! Place both of your potatoes—your experimental potato and your control potato—on a cookie sheet or other oven-safe pan.
- Put on your protective eyewear and oven mitts.
- Place both the experimental potato and the control potato in a preheated 350-degree oven and bake them for 30 minutes.
- After 30 minutes, put your protective eyewear and oven mitts back on. Clear the area where you will place the cookie sheet or pan.
- Carefully remove the cookie sheet from the oven using oven mitts or potholders.
- Using your oven mitt, hold your potato “astronaut.” Carefully insert the thermometer and take the internal temperature of your protected potato “astronaut,” then take the temperature of your control potato.
- Create a table or graph to illustrate the results, comparing your potato “astronaut” with the control potato.

### Improve

- Did the internal temperature of the protected potato “astronaut” improve over the control potato’s temperature? Why or why not?
- If no improvement was made, brainstorm and discuss with your team what you could do to improve your design. If time permits, test your new design and record your new data on your table or graph.

### Share

- Compare your team’s results with the other teams. How did your spacesuit compare to the others? What improvements could be made if you had the time?
- How is this activity similar to the development of protective spacesuits for astronauts?
- Compare and contrast between the radiation that real astronauts are exposed to in space and the radiation that your potato “astronauts” experienced.

# Radiation Exposure on Earth Worksheet

Name: \_\_\_\_\_

Date: \_\_\_\_\_

**Directions:** Estimate your annual radiation dose by adding together the amount of radiation you are exposed to from common sources of radiation. Place the value from the “Common sources of radiation” column (middle column) that corresponds to your situation in the “Annual dose” column (right column). All values are in millisieverts (mSv), which is the standard unit of measurement for a dose of radiation. Add up all the numbers in the right column to determine your total estimated annual radiation dose.

Factors	Common sources of radiation		Annual dose
Where you live	<b>Cosmic Radiation (from outer space)</b> Exposure depends on your elevation (how much atmosphere is above you to block radiation)		
	<b>Elevation</b> (Average cities' data from U.S. Geological Survey: <a href="http://usgs.gov">http://usgs.gov</a> )	<b>Value, mSv</b>	
	• <b>Sea level</b> (New York, Philadelphia, Houston, Baltimore, Boston, New Orleans, Jacksonville, Seattle)	0.26	
	• <b>1 to 1,000 feet</b> (Chicago, Detroit, San Diego, Dallas, Minneapolis, St. Louis, Indianapolis, San Francisco, Memphis, Washington DC, Milwaukee, Cleveland, Columbus, Atlanta)	0.28	
	• <b>1,001 to 2,000 feet</b> (Phoenix, Pittsburgh, San Jose, Oklahoma City)	0.31	
	• <b>2,001 to 3,000 feet</b> (Las Vegas, Los Angeles, Honolulu, Tucson)	0.35	
	• <b>3,001 to 4,000 feet</b> (El Paso)	0.41	
	• <b>4,001 to 5,000 feet</b> (Salt Lake City)	0.47	
	• <b>5,001 to 6,000 feet</b> (Denver, Albuquerque)	0.52	
	• <b>6,001 to 7,000 feet</b>	0.66	
	• <b>7,001 to 8,000 feet</b>	0.79	
	• <b>8,001 to 9,000 feet</b>	0.96	_____ mSv
	<b>Terrestrial Radiation (from the ground)</b>		
	• If you live in a state that borders the Gulf of Mexico or the Atlantic Ocean, add 0.16 mSv.		
	• If you live in the Colorado Plateau area (around Denver), add 0.63 mSv.		
	• If you live anywhere else in the continental U.S., add 0.07 mSv.		_____ mSv
	<b>House Construction</b>		
	• If you live in a stone, adobe, brick, or concrete building, add 0.07 mSv.		_____ mSv
	<b>Power Plants</b>		
	• If you live within 50 miles of a nuclear power plant, add 0.0001 mSv. (For locations of nuclear power plants, visit the United States Nuclear Regulatory Commission website: <a href="http://www.nrc.gov/info-finder.html">www.nrc.gov/info-finder.html</a> .)		
	• If you live within 50 miles of a coal-fired power plant, add 0.0003 mSv.		_____ mSv
<b>Food Water Air</b>	<b>Internal Radiation (average values)</b>		
	• From food (most food has naturally occurring radioactive carbon-14 and potassium-40) and from water (radon dissolved in water)		0.40 mSv
	• From air (radon emanating from the ground)		2.00 mSv
<b>How you live</b>	<b>Add the following values if they apply to you:</b>		
	Live near a weapons test fallout site	0.01 mSv	_____ mSv
	Jet plane travel	0.005 mSv per hour in air (total for all flights in 1 year)	_____ mSv

<b>How you live</b>	If you have porcelain crowns or false teeth	0.0007 mSv per tooth/crown (2 crowns = 0.0014 mSv)	_____ mSv
	If you wear a luminous watch	0.0006 mSv	_____ mSv
	If you watch TV	0.01 mSv	_____ mSv
	If you use a computer screen	0.01 mSv	_____ mSv
	If you have a smoke detector	0.00008 mSv	_____ mSv
	If you use a gas camping lantern	0.002 mSv	_____ mSv
	If you smoke	160.0 mSv	_____ mSv
<b>Medical tests</b>	<b>Medical diagnostic tests performed on you this year (per procedure)</b>		
	Extremity x-ray (arm, hand, foot, or leg)	0.01 mSv (if you had two x-rays, then = 0.02 mSv)	_____ mSv
	Dental x-ray	0.01 mSv	_____ mSv
	Chest x-ray	0.06 mSv	_____ mSv
	Pelvis/hip x-ray	0.65 mSv	_____ mSv
	Skull/neck x-ray	0.20 mSv	_____ mSv
	Upper gastrointestinal x-ray	2.45 mSv	_____ mSv
	Computed axial tomography (CAT) scan (head and body)	1.1 mSv	_____ mSv
	Nuclear medicine (e.g., thyroid scan)	0.014 mSv	_____ mSv
<b>Total annual dose</b>	Add up all the numbers in the last column. This is your annual radiation dose on Earth.		_____ mSv annually

### Banana Equivalent Dose (BED):

Bananas are a natural source of radioactive isotopes. A “Banana Equivalent Dose” (BED) is a unit that compares radiation exposure to the amount you naturally get from eating a banana. A lethal dose of radiation would be comparable to the radiation you would get from eating 80 million bananas! Using the following conversion, what is your BED each year? \_\_\_\_\_

1 BED = 0.001 mSv

Example:

Your annual radiation dose is 2.8514 mSv.

You will need to convert millisieverts to BEDs by multiplying your answer by 1,000.

$2.8514 \times 1000 = 2851.4$  bananas for the year

### Discussion:

- The average exposure for 1 year on Earth is about 3.0 mSv. How does your annual radiation dose compare to the average? How does your annual radiation dose compare to other students?
- The average exposure rate for astronauts on the International Space Station for a 6-month stay is 160 mSv. What is the BED for those astronauts?
- The average radiation exposure for astronauts living on the Moon for 9 days is 11.4 mSv. What is the BED for those astronauts? Why is this number less than the BED for a stay on the International Space Station?
- The estimated radiation exposure for astronauts on a 3-year round-trip mission to Mars is 1,200 mSv. What is the BED for a trip to Mars? If a lethal dose of radiation is the equivalent of eating 80 million bananas, about how many trips to Mars could you make?

# Activity Two: Isolation and Confinement

## Educator Notes

### Learning Objectives

Students will

- Research the hazards of isolation.
- Explore various analog facilities such as HERA (Human Exploration Research Analog) and NEK (Nezemnyy Eksperimental'nyy Kompleks) and studies such as SIRIUS (Scientific International Research In a Unique terrestrial Station) and USAP (U.S. Antarctic Program) and identify their research objective.
- Present a proposal that includes a company name, mission patch, and mitigation solution plan.
- Describe the ways NASA attempts to mitigate the negative effects of isolation and confinement on astronauts.

### Challenge Overview

Teams of students will form a company to research the deep space hazards of isolation and confinement using various NASA resources and research. Teams will be instructed to select two or more CONNECT (Community, Openness, Networking, Needs, Expeditionary Mindset, Countermeasures, and Training) mitigation techniques and design a solution plan and an optional prototype, a company name, a mission patch, and a proposal to “sell” their company’s idea to a simulated NASA panel.

### Suggested Pacing

120 to 180 minutes  
(up to 1 week of sessions)

### National STEM Standards

Science and Engineering (NGSS)	
<p><i>Disciplinary Core Ideas</i></p> <ul style="list-style-type: none"> <li>• MS-LS2.D: Social Interactions and Group Behavior: Group behavior has evolved because membership can increase the chances of survival for individuals and their genetic relatives.</li> <li>• MS-LS1-5: Structures and Processes: Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.</li> </ul>	<p><i>Crosscutting Concepts</i></p> <ul style="list-style-type: none"> <li>• Cause and Effect: Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.</li> </ul>
Technology (ISTE)	
<p><i>Standards for Students</i></p> <ul style="list-style-type: none"> <li>• Empowered Learner: Students leverage technology to take an active role in choosing, achieving, and demonstrating competency in their learning goals, informed by the learning sciences.</li> <li>• Digital Citizen: Students recognize the rights, responsibilities, and opportunities of living, learning, and working in an interconnected digital world, and they act and model in ways that are safe, legal, and ethical.</li> <li>• Knowledge Constructor: Students critically curate a variety of resources using digital tools to construct knowledge, produce creative artifacts, and make meaningful learning experiences for themselves and others.</li> </ul>	<p><i>Standards for Students (continued)</i></p> <ul style="list-style-type: none"> <li>• Innovative Designer: Students use a variety of technologies within a design process to identify and solve problems by creating new, useful, or imaginative solutions.</li> <li>• Creative Communicator: Students communicate clearly and express themselves creatively for a variety of purposes using the platforms, tools, styles, formats, and digital media appropriate to their goals.</li> <li>• Global Collaborator: Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally.</li> </ul>
ELA/Literacy (CCSS)	
<p><i>ELA/Literacy</i></p> <ul style="list-style-type: none"> <li>• RST.9-10.8: Assess the extent to which the reasoning and evidence in a text support the author’s claim or a recommendation for solving a scientific or technical problem. (HS-LS2-8)</li> <li>• RST.11-12.1: Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-LS2-8)</li> </ul>	<p><i>ELA/Literacy (continued)</i></p> <ul style="list-style-type: none"> <li>• RST.11-12.7: Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, and multimedia) in order to address a question or solve a problem. (HS-LS2-8)</li> <li>• RST.11-12.8: Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-LS2-8)</li> </ul>

### Challenge Preparation

The educator should

- Read the introduction and background information and Educator Notes.

- Review “Houston We Have a Podcast, Episode 58: Hazard 2: Isolation.” Note: Educators may opt to assign this as listening homework ahead of time. A time stamp document is included after the Student Handbook.
- Review the CONNECT mitigation techniques that are defined and discussed in the podcast and review the CONNECT Table in the Explore Knowns and Unknowns section of the Educator Notes.
- Assemble materials or provide a list of materials students can use.
- Have videos preloaded for presentation.
- Provide computer access to students.
- Provide podcast links and optional time stamp documents to students:
  - Houston, We Have a Podcast, Episode 58: Hazard 2: Isolation (1 hour): [www.nasa.gov/johnson/HWHAP/hazard-2-isolation](http://www.nasa.gov/johnson/HWHAP/hazard-2-isolation)
  - Houston, We have a Podcast, Episode 162: CONNECT During Social Isolation (1 hour): <https://www.nasa.gov/johnson/HWHAP/connect-during-social-isolation>

### Handouts

- Student Handout (one per team)
- Straight From the Source: Dr. Thomas Williams (one per student)
- CONNECT Table and Resources for Students (one per team)
- Time Stamps for “Houston We Have a Podcast: Isolation” (one per student)
- Time Stamps for “Houston We Have a Podcast: CONNECT During Social Isolation” (one per student)

### Materials

- Writing utensils
- Poster boards or recording devices to present final company name, patch design, and proposal presentations and/or promotional video
- Creative art supplies (markers, scissors, rulers, protractors, glue, old magazines, stickers, etc.)
- Requested items from team for construction if the team decides to make a prototype

### Safety

- Students should be aware of their surroundings and carefully move throughout the room when viewing other teams’ work.
- Before using scissors, discuss safety issues surrounding proper use.

### Introduce the Challenge

- Provide context for this activity using the introduction and background information in this guide.
- To activate students’ prior knowledge, ask students to define “hazard” in their own words. Then, have students list some potential hazards of deep space travel for astronauts. After several possibilities have been presented by students, write the acronym “RIDGE” as well as each of the concepts for which it stands: Radiation, Isolation and confinement, Distance from Earth, Gravity (or lack thereof), and hostile/closed Environments. Compare and contrast the student-generated list with NASA’s list.
- Ask students this question: What would be your biggest hazard concern as a deep space astronaut? Have them share in discussion teams.
- Have students listen to “Houston We Have a Podcast, Episode 58: Hazard 2: Isolation.”

Note: It is recommended to assign this podcast as a homework assignment prior to the activity; otherwise, be sure to account for the time (approximately 1 hour) to have students listen and take notes or play the episode in sections over a week. A transcript is available at the link provided (see Challenge Preparation) and can be printed and distributed for students who might need it.

- Divide the students into teams (three students per team is ideal) and distribute the Student Handout to each team. Explain the details of the challenge, including the design criteria and constraints and the expectations for teamwork and classroom management.

## Hazards to Deep Space Astronauts

### NASA, We Have an Isolation Problem

- Share the following scenario with students:

NASA has approached your company to help with the mitigation of a major hazard for deep space astronauts: isolation and confinement. How will we protect our astronauts during their deep space travels to Mars and back? Specifically, how will we protect them from the effects of isolation and confinement away from their home planet, Earth? Your company team will need to work together to develop a proposal to present to a simulated NASA panel. Included in your proposal must be your company's name, a mission patch design, a solution plan and optional prototype design of your CONNECT mitigation techniques for isolation and confinement, the initial analog facility or location for research, and the types of tests you will conduct to demonstrate validity.
- Explain to students that an analog is a situation on Earth that produces effects on the body similar to those experienced in space—physical, mental, and emotional. These studies help prepare for long-duration missions. NASA is associated with at least 14 analog missions throughout the world. [www.nasa.gov/analogs/types-of-analogs](http://www.nasa.gov/analogs/types-of-analogs)
- Review the following criteria and constraints of the activity with students:

Criteria	Constraints
Design a solution plan that focuses on at least two of the seven CONNECT mitigations.	No real-time connections can be used in this design. Due to distance from Earth there will be a delay in any communications. (Note: "Real time" refers to the actual time during which a process or event occurs.)
Design must be identified with a creative acronym (e.g., "D-SMILE" for Deep-Space Mitigation on Isolation's "Lurking" Effects) and patch design.	
Design must be backed up with Human Research Program research.	
Describe which Earth analog facility (e.g., HERA) would best simulate a trip to deep space and what tests would be conducted here on Earth before the first deep space mission.	
Create a presentation to propose your company's mitigation solution plan to simulated NASA panel.	

### Facilitate the Challenge

#### ? Meet the Problem

- Present this idea to students and have a large group discussion:

Thinking back, have you ever felt confined and isolated in a particular situation? (Possible answers: During a pandemic, accidentally getting left behind, time spent away from home at a summer camp, etc.) How did you feel? If you felt stressed, what did you do to feel less stressed? Now imagine you are on a journey to deep space. How would you feel if you were not able to see or communicate in real time with your family and friends for months or even years?
- Show students the video "Isolation and Confinement":  
[www.youtube.com/watch?v=FPinASEKA\\_I&feature=youtu.be](https://www.youtube.com/watch?v=FPinASEKA_I&feature=youtu.be)

### Share With Students



### Brain Booster

Extended-duration missions on the International Space Station are stepping-stones to future missions to the Moon and Mars.

Learn more: [www.nasa.gov/1ym](http://www.nasa.gov/1ym)



### On Location

The Human Exploration Research Analog (HERA), located at Johnson Space Center, is a unique three-story habitat designed to serve as an analog for isolation, confinement, and remote conditions in exploration scenarios. Take the 3D tour if you have time!



Learn more:

[www.nasa.gov/analogs/hera](http://www.nasa.gov/analogs/hera)

- Discuss the importance of NASA and the astronaut selection process, which looks for individuals who demonstrate high-performing characteristics such as resilience and adaptability.

### Explore Knowns and Unknowns: Research

- After students have listened to the podcasts (educator decision), teams will break into jigsaw groups where a team member will become the “expert researcher” on one of the three topics below and report their findings back to their team. Students will use the handout “Straight From the Source: Dr. Thomas Williams” along with the research websites listed here.
  1. Side effects and mitigation techniques: What are some human side effects and possible mitigation techniques of isolation and confinement that have been observed in ongoing Human Research Program studies and during the pandemic?
    - Houston We Have a Podcast: CONNECT During Social Isolation. [www.nasa.gov/johnson/HWHAP/connect-during-social-isolation](http://www.nasa.gov/johnson/HWHAP/connect-during-social-isolation)
  2. Astronaut selection: What are some qualities that NASA looks for when selecting astronauts for long-duration space missions?
    - NASA astronaut selection: [www.nasa.gov/content/astronaut-selection-program](http://www.nasa.gov/content/astronaut-selection-program)
    - Expeditionary skills for astronauts: [www.nasa.gov/audience/foreducators/stem-on-station/expeditionary-skills-for-life.html](http://www.nasa.gov/audience/foreducators/stem-on-station/expeditionary-skills-for-life.html)
  3. Analogs: What are some NASA analogs on Earth, and what are their research objectives?
    - NASA analog missions: [www.nasa.gov/analogs/what-are-analog-missions](http://www.nasa.gov/analogs/what-are-analog-missions)
    - NEK and SIRIUS: [www.nasa.gov/analogs/nek/about](http://www.nasa.gov/analogs/nek/about)
    - USAP: [www.nasa.gov/hrp/research/analogs/antarctica](http://www.nasa.gov/hrp/research/analogs/antarctica)
- Once the initial research phase is complete, have “expert researchers” come back together with their initial team to share their research with team members.

### Generate Possible Solutions

- Have students continue research as teams to explore the CONNECT acronym and possible mitigations. Teams will use the CONNECT Table to identify, define, and provide examples for each part of CONNECT.

**CONNECT Table**

Mitigation	Definition	Examples
<b>C</b> Community	Being a part of something	Eating together, community chores
<b>O</b> Openness	Open to adaptations, changes	Trying a new food or music every week and journaling feelings along the way
<b>N</b> Networking	Connecting with family and friends	Not-in-real-time games, where players can continue playing at their leisure (e.g., Words With Friends, chess)
<b>N</b> Needs	Meeting physiological and emotional needs	Work out both muscles and brain, hobby, a reactive pet
<b>E</b> Expeditionary Mindset	A fixed attitude, disposition, or mood with the task in the forefront of one's mind	Teamwork, design a team-building exercise, mission-driven focus
<b>C</b> Countermeasures	An action taken to counteract a danger or threat	Self-awareness, journaling, physiological tests, reaction time tests help monitor sleep deprivation
<b>T</b> Training	The action of teaching a person a particular skills or behaviors for a successful mission	Reading up on and staying informed on deep space mission goals along the journey, virtual reality, mission-driven focus



## Hazards to Deep Space Astronauts

- Have student teams agree upon at least two of the seven CONNECT mitigation focus points. Remind them that they will be proposing a solution plan that will mitigate the negative effects of being isolated and confined during an astronaut's deep space journey.
- Have students brainstorm ideas on how to maintain mental wellness and not feel as isolated. Encourage creativity but also refer to the criteria and constraints.
- Have students put themselves in an isolated situation: "Imagine your group is in an analog mission location. You are isolated from your friends and family and society for 3 months. How do you feel, and how do you cope?"
- Student teams will then work to develop a creative acronym for their team name, along with a mission patch design (see criteria for company name).
- Show the NASA eClips video "Our World: Mission Patches": [nasaclips.arc.nasa.gov/video/ourworld/our-world-mission-patches](https://nasaclips.arc.nasa.gov/video/ourworld/our-world-mission-patches).  
Note: Tips and examples for creating mission patches can be found in this teacher guide from the 2019 NASA/Tynker™ Mission Patch Design Challenge: [www.tynker.com/hour-of-code/nasa-mission-patch-guide.pdf](http://www.tynker.com/hour-of-code/nasa-mission-patch-guide.pdf)
- Student teams will create a list of common materials for their solution plan and optional prototype design (if they decide to make one). Students may bring appropriate items from home if needed.

### ?? Consider Consequences

- Based on the team's selected CONNECT mitigation focus points, have students come up with a solution plan with suggested CONNECT activities. If the team has also elected to make a prototype design, students will assemble or sketch their prototype design with requested materials.
- Have students refer to the Human Research Program tests and research various analog/environmental tests to identify whether their solution plan or prototype can be used effectively.
- Have students answer the following questions as a team during their research:
  - How are current astronauts and current analog participants tested to see that they are in good health?  
[www.nasa.gov/analogs/what-are-analog-missions](http://www.nasa.gov/analogs/what-are-analog-missions)
  - What are some ways that NASA measures astronauts' stress levels?
  - What is the Psychomotor Vigilance Self Test (reaction self test) and what is its importance? If time allows, have students take a version of this online test and compare their results with other team members.
  - How will your CONNECT mitigations be tested for validity on current analog participants here on Earth before a deep space mission?



### Present Findings

After teams have completed their solution plan (and prototype design, if they have chosen to create one), they will present their proposal to a simulated NASA panel. It is recommended that the educator bring in others to form the panel. The educator can also nominate one team member from each team to be part of the panel. They will not be allowed to judge or rate their own team's ideas.

Engage students with the following discussion questions:

- Discuss the mitigation focus points (CONNECT) that are represented in your team's design.
- How will your solution plan and optional prototype design mitigate isolation's negative effects?
- What types of tests will be administered to astronauts to see if the various mitigation techniques are effective? Discuss tests in analog locations as well as in deep space.
- What were your team's struggles during the design process?
- What types of current research are being conducted for deep space travel?
- Isolation and pandemic connections:



- Compare and contrast your experience during isolation and/or confinement situations in your life with the research being conducted on the effects of deep space travel on astronauts.
- In your team’s opinion, would any of these solution plans and optional prototypes be helpful during a pandemic or in a location on Earth where one must isolate from others for a significant amount of time?

### **Proposal Presentation Checklist**

It is recommended that the educator use the following checklist to evaluate the final proposal presentation. The educator may also give the checklist to student teams as they are working on their project.

- Team company name: Must be a creative acronym that resembles the team’s proposal
- Team company mission patch: Must represent the company’s mission and follow the guidelines for making a patch (see NASA eClips video “Our World: Mission Patches”)
- Background research writeup with culminating background research on one page
- Team CONNECT selections along with the activities/illustrations/prototype that go with each selection
- Team proposal for analog testing facility and how the team’s solutions will be tested before a deep space mission

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

### **Improve**

- Have students take constructive criticism from the simulated NASA panel.
- Have students review and modify or improve their design for a final critique from the main educator.

### **Extensions**

- Have students design a page to market their solution plan and optional prototype.
- Have students research NASA resources that directly tie to deep space and pandemics and write up recommendations to help prevent the negative effects of isolation based on their findings.
  - An Astronaut’s Tips for Living in Space: [www.nasa.gov/feature/an-astronaut-s-tips-for-living-in-space-or-anywhere](http://www.nasa.gov/feature/an-astronaut-s-tips-for-living-in-space-or-anywhere)
- Ask students, “How might NASA’s Human Research Program be applied to other careers on Earth or to product and technology spinoffs?” (Possible answers: Military careers, technology for submarines or oil rigs, products for the aging population, etc.)
- Allow students to dive deeper into research analogs such as HERA and the U.S. Antarctic Program. Ask students, “Would you want to be a human subject? Why or why not?”
  - NASA Seeking U.S. Citizens for Social Isolation Study for Moon and Mars Missions: [www.nasa.gov/feature/nasa-seeking-us-citizens-for-social-isolation-study-for-moon-and-mars-missions/](http://www.nasa.gov/feature/nasa-seeking-us-citizens-for-social-isolation-study-for-moon-and-mars-missions/)

### **Reference**

Project X-51 Contest: [www.nasa.gov/stem-ed-resources/project-x-51.html](http://www.nasa.gov/stem-ed-resources/project-x-51.html)

## Activity Two: Isolation and Confinement

### Student Handout

#### Your Challenge

#### NASA, We Have an Isolation Problem

NASA has approached your company to help with the mitigation of a major hazard for deep space astronauts: isolation and confinement. How will we protect our astronauts during their deep space travels to Mars and back? Specifically, how will we protect them from the effects of isolation and confinement far from our home planet, Earth? Based on various NASA resources and research, your team will select two or more CONNECT mitigation techniques and design a solution plan and optional prototype, a company name, a mission patch, and a proposal to “sell” your company’s idea to a simulated NASA panel.

Your proposed solution must meet the following criteria and constraints:

Criteria	Constraints
Design a solution plan that focuses on at least two of the seven CONNECT mitigations.	No real-time connections can be used in this design. Due to distance from Earth there will be a delay in any communications. (Note: “Real time” is the actual time during which a process or event occurs.)
Design must be identified with a creative acronym (e.g., “D-SMILE” for Deep-Space Mitigation on Isolation’s “Lurking” Effects) and patch design.	
Design must be backed up with Human Research Program research.	
Describe which Earth analog facility (e.g., HERA) would best simulate a trip to deep space and what tests would be conducted here on Earth before the first deep space mission.	
Create a presentation to propose your company’s mitigation solution plan to simulated NASA panel.	

#### ? Meet the Problem

Discussion time: Thinking back, have you ever felt confined and isolated in a particular situation? (Possible answers: During a pandemic, accidentally getting left behind, time spent at a summer camp, etc.) How did you feel? If you felt stressed, what did you do to feel less stressed? Now imagine you are on a journey to deep space. How would you feel if you were not able to see or communicate in real time with your family and friends for months or even years?

#### 🔍 Explore Knowns and Unknowns

- After listening to podcasts, your team will break into jigsaw groups where a team member will become the “expert researcher” on one of the three topics below and report back to your team members. Use the handout “Straight From the Source: Dr. Thomas Williams” and the research links provided.
  - Side effects and mitigation techniques: What are some human side effects and possible mitigation techniques of isolation and confinement that have been observed in ongoing Human Research Program studies and during the pandemic?

#### Fun Fact

“The Martian” merges fictional and factual narratives about Mars, building on the work NASA and others have done and moving it forward into the 2030s, when NASA astronauts regularly travel to Mars to explore and live on its surface. Although the action takes place 20 years in the future, NASA is already developing many of the technologies that appear in the book and film. NASA is also developing strategies to reduce risk factors for Mars astronauts isolated and confined far from Planet Earth.



Learn more:

[www.nasa.gov/feature/nine-real-nasa-technologies-in-the-martian](http://www.nasa.gov/feature/nine-real-nasa-technologies-in-the-martian)

#### Career Corner

Dr. Tom Williams is the element scientist for NASA’s Human Factors and Behavioral Performance (HFBP) division. Affiliated with Johnson Space Center since 2015, Tom directs a multidisciplinary team of scientists focused on human factors in the areas of habitability, mission processes and tasks, human automation robotic interactions, dynamic loads, and training, as well as spaceflight risks related to behavioral medicine, sleep and fatigue, and team performance.



Learn more:

[www.nasa.gov/hrp/elements/hfbp/leadership-team](http://www.nasa.gov/hrp/elements/hfbp/leadership-team)

- Houston We Have a Podcast: CONNECT During Social Isolation [www.nasa.gov/johnson/HWHAP/connect-during-social-isolation](http://www.nasa.gov/johnson/HWHAP/connect-during-social-isolation)
- 2. Astronaut selection: What are some qualities that NASA looks for when selecting astronauts for long-duration space missions?
  - NASA astronaut selection: [www.nasa.gov/content/astronaut-selection-program](http://www.nasa.gov/content/astronaut-selection-program)
  - Expeditionary skills for astronauts: [www.nasa.gov/audience/foreducators/stem-on-station/expeditionary-skills-for-life.html](http://www.nasa.gov/audience/foreducators/stem-on-station/expeditionary-skills-for-life.html)
- 3. Analogs: What are some NASA analogs on Earth, and what are their research objectives?
  - NASA analog missions: [www.nasa.gov/analogs/what-are-analog-missions](http://www.nasa.gov/analogs/what-are-analog-missions)
  - NEK and SIRIUS: [www.nasa.gov/analogs/nek/about](http://www.nasa.gov/analogs/nek/about)
  - USAP: [www.nasa.gov/hrp/research/analogs/antarctica](http://www.nasa.gov/hrp/research/analogs/antarctica)
- Once the initial research phase is complete, your team will come back together and “expert researchers” will share their research with their entire team.

### **Generate Possible Solutions**

- Next, you will research further into CONNECT mitigations. What are the CONNECT mitigation focus points? Work as a team to fill out the CONNECT Table provided with the student handouts.
- Agree upon at least two of the seven CONNECT mitigation focus points. Remember that you will be proposing a solution plan that will mitigate the negative effects of being isolated and confined during an astronaut’s deep space journey.
- Brainstorm ideas on how to maintain mental wellness and not feel as isolated. Be creative but also refer to the criteria and constraints.
- Now that you have done some initial research, work as a team to develop a design to mitigate the negative effects of isolation. Your design, once complete, must follow the criteria and constraints.
- Put yourself in a deep space astronaut’s boots or an analog participant’s shoes. Discuss what team members did during the pandemic in 2020 and 2021. Be creative and refer to the criteria and constraints.
- Develop an acronym team name and design a mission patch (see criteria for name and patch).
- Create a list of materials your team will need and submit those to your instructor. If items are not provided, team members may bring appropriate items from home.

### **Consider Consequences**

- Based on the team’s selected CONNECT mitigation focus points, come up with a solution plan with suggested CONNECT activities. If your team has also elected to make a prototype design, you will assemble or sketch their prototype design with requested materials.
- Refer to the NASA Human Research Program tests. Your team will research various NASA analog/environmental tests to identify whether your solution plan or optional prototype can be used.
- Answer the following questions:
  - How are current astronauts and current analog participants tested to determine that they are in good health? [www.nasa.gov/analogs/what-are-analog-missions](http://www.nasa.gov/analogs/what-are-analog-missions)
  - What are some ways that NASA measures the stress level of its astronauts?
  - What is the Psychomotor Vigilance Self Test (reaction self test)? Why is it important? Research and take a version of this test online. Compare your results with your team.
  - How will your CONNECT mitigations be tested for validity on current analog participants here on Earth before a deep space mission?

## Hazards to Deep Space Astronauts



### Present Findings

Address the following topics in your team presentation to the simulated NASA panel:

- Discuss the mitigation focus points (CONNECT) that are represented in your team's design.
- How will your solution plan and optional prototype design mitigate isolation's negative effects?
- What types of tests will be administered to astronauts to see if the various mitigation techniques are effective? Discuss tests in analog locations as well as in deep space.
- What were your team's struggles during the design process?
- What types of current research are being conducted for deep space travel?
- Isolation and pandemic connections:
  - Compare and contrast your experience during isolation and/or confinement situations in your life with the research being conducted on the effects of deep space travel on astronauts.
  - In your team's opinion, would any of these solution plans and optional prototype designs be helpful during a pandemic or in a location on Earth where one must isolate from others for a significant amount of time?

### ***Proposal Presentation Checklist***

- Team company name: Must be a creative acronym that resembles the team's proposal
- Team company mission patch: Must represent the company's mission and follow the guidelines for making a patch (see NASA eClips video "Our World: Mission Patches")
- Background research writeup with culminating background research on one page
- Team CONNECT selections along with the activities/illustrations/prototype that go with each selection
- Team proposal for analog testing facility and how the team's solutions will be tested before a deep space mission



### Improve

- After your NASA panel presentation is complete, your team should take the constructive criticism you received from the "NASA Panel" and modify or improve your team's design for final critique from your lead educator.

# CONNECT Table and Resources for Students

Mitigation	Definition	Examples
<b>C</b> Community		
<b>O</b> Openness		
<b>N</b> Networking		
<b>N</b> Needs		
<b>E</b> Expeditionary Mindset		
<b>C</b> Countermeasures		
<b>T</b> Training		

## Resources for Students

Conquering the Challenge of Isolation in Space (NASA Spinoffs): [www.nasa.gov/feature/conquering-the-challenge-of-isolation-in-space-nasa-s-human-research-program-director](http://www.nasa.gov/feature/conquering-the-challenge-of-isolation-in-space-nasa-s-human-research-program-director)

Social Isolation and Space: [www.nasa.gov/hrp/social-isolation/in-context](http://www.nasa.gov/hrp/social-isolation/in-context)

Self-Test Webpage: [www.nasa.gov/mission\\_pages/station/research/experiments/explorer/Investigation.html?id=955](http://www.nasa.gov/mission_pages/station/research/experiments/explorer/Investigation.html?id=955)

Human Research Program: [www.nasa.gov/hrp/elements/hfbp](http://www.nasa.gov/hrp/elements/hfbp)

Human Research Roadmap: [humanresearchroadmap.nasa.gov/explore/](http://humanresearchroadmap.nasa.gov/explore/)

Interview Video: Dr. Tom Williams: [www.youtube.com/watch?v=P1FYk1kdh4](http://www.youtube.com/watch?v=P1FYk1kdh4)

A good example of a Psychomotor Vigilance Test: [www.sleepdisordersflorida.com/pvt1.html#responseOut](http://www.sleepdisordersflorida.com/pvt1.html#responseOut)

Other self-test examples: [humanbenchmark.com/](http://humanbenchmark.com/)

Human Research Program Proposals: [www.nasa.gov/feature/nasa-selects-21-research-proposals-to-advance-human-space-exploration/](http://www.nasa.gov/feature/nasa-selects-21-research-proposals-to-advance-human-space-exploration/)

Background on Expeditionary Skills for Astronauts: [www.nasa.gov/audience/foreducators/stem-on-station/expeditionary-skills-for-life.html](http://www.nasa.gov/audience/foreducators/stem-on-station/expeditionary-skills-for-life.html)

# Straight From the Source: Dr. Thomas Williams

NASA STEM Engagement staff interviewed NASA scientist Dr. Thomas Williams via email in November 2020.

### 1. Are there specific traits that NASA looks for in astronauts to be considered good “deep space” candidates?

The primary traits NASA looks for in preventing issues with being isolated are very close to the traits that help a team of students work together. We can place these traits under the following categories: the ability to relate well to one another, to be good team players and considerate of one another (good group-living skills), to be positive with one another, to respect the reality that sometimes each of us needs quiet time (a little privacy), we need to self-regulate our emotions if things don't go our way, and we need to be able to recognize that we serve as, in essence, an extended family away from our primary families (we laugh together, share joys and disappointments and excitements in a way that promotes the good of each other). It's always important to acknowledge that there may be conflict in any human relationship. There's an old saying that psychologists have: “Good mental health is not the absence of conflict between two people, but rather how you handle the conflict.” We also spend a lot of time training our astronauts on living together in close quarters like a spacecraft, similar to what we're all now doing in our homes during the pandemic. We train our astronauts to be alert for, and avoid, “criticizing each other,” showing “contempt” for each other (by putting each other down, talking down to each other, not respecting their differences), by being “defensive” if a member of our team points out that we have done something wrong; and then if we get upset with one another, “stonewalling,” by not talking to them, or ignoring each other. We might all do one or two of these, we're all human. But trouble in any relationship starts when we start to do all four of these regularly with others at home, at school, during extracurricular activities, or in a small spacecraft.... That starts to damage our relationships, and whether you're on Earth or in a small spacecraft, it's much better to just be getting along with one another, feeling positive, and being open to the adventure of learning or adventure of space travel.

### 2. Any specific Human Research Project (HRP) studies targeting mental state of isolation on humans?

NASA Human Research Program funds several studies focused on better understanding how well humans can handle isolated environments with an interest in understanding how these isolated, confined, extreme (ICE) environments may impact our crews in a long-duration space exploration. We fund research with scientists and other individuals who “winter-over” in Antarctica for 12 or more months. What we have learned is that humans often experience what is called “**winter-over syndrome**.” That means these individuals start to withdraw from one another (social narrowing and social withdrawal) by increasingly spending more time alone in their rooms. That would be difficult on a small spacecraft. They also start to express more tension, irritability, and somatic complaints (more aches and pains). If a crewmember starts to have increased medical complaints, they're too far from Earth to get the great medical care we have here in Houston. They also become more territorial—when they put something down, they don't want anyone else to move it. Some things they complain of—feeling down or depressed, have problems concentrating, sleeping, and problems with their memory. You can see why it's so important for NASA to understand how long-term isolation may impact our crew. But we don't know for sure this is something our crew will experience—but we need to be ready to help them if they do. That is why we use these studies to understand what “might” happen, and then we can develop countermeasures to help our crew if they start to experience these types of problems.

### 3. Any “safe” activities that come to mind when testing an astronaut's state of mind that we might be able to use in our K–12 STEM activities?

One “safe” activity that comes to mind that can be used is exercises to increase our self-awareness to be alert to our own feelings. In our research we spend a lot of time and effort to assess “how the astronauts are feeling.” Understanding how we're feeling alerts us to how our feelings help us mobilize and coordinate our actions; and that helps ensure our crew can carry out their performance requirements. That's why our isolation research focuses on assessing the mood and emotions of our crews, because it helps us determine how the long-duration social isolation impacts on how they're feeling—and how they're feeling helps determine how they'll perform. So, a safe activity that helps enhance performance is to carry out a “self-check” on how different activities may activate different moods and emotions and use that increased awareness to then help shape our feelings about activities. For example, if approaching certain STEM problems seem harder than others, being alert to the feelings of “not getting it” can help us activate a mood or emotion to strive toward “mastery” of the problem rather than a feeling of being unprepared. That's what learning should be like.

# Time Stamps for “Houston We Have a Podcast: Isolation”

This 58-minute podcast is available at [www.nasa.gov/johnson/HWHAP/hazard-2-isolation](http://www.nasa.gov/johnson/HWHAP/hazard-2-isolation). Use the following time stamps to quickly locate the topics you would like to research.

Start time, min:sec	End time, min:sec	Topic
0	1:15	Introduction
1:15	4:38	What is isolation, and its negative effects on humans—Dr. Tom Williams
4:38	6:30	Tests in the 1960s on social deprivation
6:30	8:24	Astronaut Shannon Lucid—Mir Space Station and books
8:24	10:40	Time delay—Astronaut Dr. Mike Barratt
10:40	12:05	Deep space time delay—Communication autonomy
12:05	13:40	Crew schedules and adjustments for deep space versus the International Space Station
13:40	15:30	Where does isolation come in for an astronaut day-to-day?
15:30	16:20	Psychological connections and changes of behavior—Mars 520 analog
16:20	17:10	Do you feel isolated on the International Space Station?—Astronaut Mike Barratt
17:10	20:00	Analog studies on behavioral changes for long-duration space missions: Human Exploration Research Analog (HERA)
20:00	25:00	HERA versus International Space Station research on sleep
25:00	27:38	Countermeasures: Sleep—Medicine and light study
27:38	29:22	Isolation and sleep balance
29:22	32:00	Analogs on Earth—Submarines, oil rigs, extreme environments
32:00	33:30	International Space Station research—Best analog for deep space—Hazards included
33:30	35:00	Oil rigs—Sleep cycle, high-performing individuals
35:00	36:30	High-performing individuals are used for analogs
36:30	38:10	Dr. Tom Williams—Background
38:10	40:50	Astronaut selection process
40:50	44:50	32 risks for long-duration spaceflight—Research, studies, and countermeasures
44:50	48:00	Acceptable amount of risks for mission success
48:00	51:00	Monitoring the astronauts—Journaling and predictions studies
51:00	52:00	How does the mind adapt to isolation?
52:00	56:00	What will deep space astronauts do on their mission to keep them at high performance and engaged? Training during journey



# Time Stamps for “Houston We Have a Podcast: CONNECT During Social Isolation”

This 65-minute podcast is available at [www.nasa.gov/johnson/HWHAP/connect-during-social-isolation](http://www.nasa.gov/johnson/HWHAP/connect-during-social-isolation). Use the following time stamps to quickly locate the topics you would like to research.

Start time, min:sec	End time, min:sec	Topic
0	2:30	Introduction: Pandemic and astronauts on long space missions—Using CONNECT in our own lives
2:30	4:03	What is social isolation? Introduction by Dr. Tom Williams
4:03	6:00	What are the results of social isolation versus feeling lonely?
6:00	8:05	Symptoms of what can come from social isolation; survey
8:05	11:45	Human spaceflight relates to social isolation (Hazards of Deep Space) in analogs and side effects
11:45	15:10	Social isolation in groups (crews and families)—Stressors
15:10	17:14	Parallels and CONNECT acronym—Seven stress reduction strategies
17:14	19:05	C—Community
19:05	20:45	Themes in Community: Positivity and purpose of surroundings (example: wearing a mask); “We are all in this together
20:45	23:10	O—Openness
23:10	25:00	Techniques to help with Openness: Mindfulness training, self-assessments, handling conflict
25:00	26:20	Nurturing the positive environment
26:20	30:30	N—Networking: Connecting with the ones we love
30:30	32:30	Astronaut networking on the International Space Station; Public Affairs Office events and celebrities
32:30	33:05	Delays in signal
33:05	38:08	N—Needs: Attending to the physiological, emotional, and psychological needs; self-care and team care
38:08	39:50	Physiological needs: Arranging their environment to meet needs
39:50	42:14	E—Expeditionary Mindset
42:14	45:30	How can we use Expeditionary Mindset to help with an end date? Set objectives that are attainable and share our successes.
45:30	48:44	C—Countermeasures. Help us maintain a sense of control
48:44	53:00	What ways can we sustain these CONNECTs when isolation does not seem to end? Reframe it! Mindfulness, journaling, how can you grow from the situation?
53:00	57:00	T—Training and Preparation. Experiences allow for growth; life has prepared us for this.
57:00	1:00:20	CONNECT: What are the impacts of social isolation? Isolation confronts that in our lives; we need to be innovative to connect. People live longer when you can connect. Happiness is connected to our health and spreads from person to person.
1:00:20	1:04:57	Space studies—Relevance to COVID-19 Value for human spaceflight—Fostering human connections



# Activity Three: Distance

## Educator Notes

### Learning Objectives

Students will

- Construct a scale model of the Earth–Moon and Earth–Mars systems depicting planetary size and distance from each other.
- Calculate the water needs of astronauts on a deep space mission.
- Calculate and graph water consumption rates and make determinations based on trends within a graph.

### Challenge Overview

Students begin by exploring the relative sizes of the Earth, Moon, and Mars and the distances between them to understand how much more of a challenge it is to send an astronaut crew to Mars than to the Moon. Students are given a scenario in which their Mars-bound spacecraft suffers a malfunction and the efficiency of its water recycling system is decreased. Students will research and investigate the water consumption rates of astronauts and determine if their current water supply is enough to sustain them on the remainder of their journey.

### Suggested Pacing

60 to 90 minutes

### National STEM Standards

Science and Engineering (NGSS)	
<i>Disciplinary Core Ideas</i>	
<ul style="list-style-type: none"> <li>• MS-ESS1-3: Analyze and interpret data to determine scale properties of objects in the solar system.</li> </ul>	
Technology (ISTE)	
<i>Standards for Students</i>	<i>Standards for Students (continued)</i>
<ul style="list-style-type: none"> <li>• Computational Thinker 5b: Students collect data or identify relevant data sets, use digital tools to analyze them, and represent data in various ways to facilitate problem solving and decision making.</li> </ul>	<ul style="list-style-type: none"> <li>• Innovative Designer 4a: Students know and use a deliberate design process for generating ideas, testing theories, creating innovative artifacts, or solving authentic problems.</li> </ul>
Mathematics (CCSS)	
<i>Mathematical Practices</i>	<i>Mathematical Practices (continued)</i>
<ul style="list-style-type: none"> <li>• CCSS.MATH.CONTENT.8.F.B.4: Construct a function to model a linear relationship between two quantities. Determine the rate of change and initial value of the function from a description of a relationship or from two (x,y) values, including reading these from a table or from a graph. Interpret the rate of change and initial value of a linear function in terms of the situation it models and in terms of its graph or table of values.</li> <li>• CCSS.MATH.CONTENT.7.EE.B.4: Use variables to represent quantities in a real-world or mathematical problem and construct simple equations and inequalities to solve problems by reasoning about the quantities.</li> </ul>	<ul style="list-style-type: none"> <li>• CCSS.MATH.CONTENT.6.RP.A.1: Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities.</li> <li>• CCSS.MATH.CONTENT.6.NS.B.3: Fluently add, subtract, multiply, and divide multidigit decimals using the standard algorithm for each operation.</li> </ul>

### Activity Preparation

The educator should

- Read the introduction and background information, Educator Notes, and Student Handout to become familiar with the activity.
- Gather and prepare all necessary supplies on the materials list.
- Arrange students in teams of two to four and distribute supplies to each group.

### Materials

For each group:

- Printed Student Handout and Data Files
- 9-inch balloons, 3 (blue or green for Earth, white or yellow for the Moon, and red or orange for Mars)
- Metric rulers or measuring tape
- Several sheets of graph paper

## Hazards to Deep Space Astronauts

- Calculator
- Colored pencils

### Safety

- Students should be aware of their surroundings and move carefully throughout the room when viewing other teams' work.
- Caution should be used when inflating balloons.

### Introduce the Challenge

- Display a balloon inflated to a diameter of 20.0 cm and tell students that it represents the size of the Earth. Ask student teams to inflate their "Earth" balloons to a size of 20.0 cm in diameter and tie them. Next, ask teams to inflate their Moon and Mars balloons (without tying them) to what they believe would be the proper scale size, based on their Earth balloons. Now have students look around the room and compare their Moon and Mars balloons to those of other students.
- Have each team use the data in Table 1 in the Student Handout to find the scale of their Earth balloon. Next, have them use that scale to complete Table 1 and inflate their Moon and Mars balloons to the proper diameter. Have students round to the nearest centimeter. (Answers are given here in bold).
- In Table 1 and the calculations that follow, the real diameters of the celestial bodies are listed to the nearest whole number. All other numbers are rounded to the nearest tenth of a centimeter for consistency.

Table 1

Body	Diameter, km	Balloon model diameter, cm
Earth	12,756	20.0
Moon	3,476	<b>5.5</b>
Mars	6,792	<b>10.6</b>

- To find the scale of the Earth balloon, divide the diameter of the Earth in kilometers (12,756) by the diameter of the balloon model in centimeters (20.0).
- $12,756/20.0 = 637.8$  (**which rounds up to 638 for simplicity**). To find the diameters for the other two balloon models, divide the actual diameter by the scale of the Earth model that was just calculated.
- Now that each team has properly inflated Earth, Moon, and Mars balloons, have students model how far away they think the Moon should be from Earth. Have them look around the room to compare their Earth-to-Moon distances with those of other students.
- Using the same scale calculated before (638 km in the real world = 1 cm in the scale world), have students complete the first line of Table 2 to find the proper scale distance between their Earth and Moon balloons.

Table 2

Bodies	Approximate distance, km	Balloon model distance, cm
Earth to Moon	384,000	<b>601.9 (6.019 m)</b>
Earth to Mars	78,300,000	<b>123,000 (1.23 km)</b>

To find the distance between each of the models, divide the actual approximate distance by the scale of the balloon models.

- Next, have students model the scale distance by holding their Earth and Moon balloons about 6 m apart. Explain to them that this distance represents the distance from the Earth to the Moon. This is the distance astronauts had to travel during the Apollo missions of the late 1960s and early 1970s and will have to travel again for the Artemis missions to the Moon. The trip takes about 3 days each way, or about the same time it takes to drive from the east coast to the west coast of the United States.
- Next, students will model how far away they think Mars should be from Earth. Have them look around the room to compare their Earth-to-Mars distances with those of others.

- Have students complete the second line of Table 2 to find the scale distance between their Earth and Mars balloons. Ask students if they can model it within the room. Can they model it in the hallway? Could they even model it on campus? Explain to students that for their models to be at the proper scale, they would have to be **1.23 km** apart, or just over 3/4 of a mile. This demonstration shows just how much farther Mars is from the Moon. Instead of a 3-day journey, like the trip from Earth to the Moon, a journey from Earth to Mars will take at least 6 months.
- Explain to students that during a journey to Mars, the spacecraft coasts through space. It cannot stop, turn around, or meet up with another vessel to resupply. All the resources needed for the entire trip to Mars must be brought with the crew. They cannot be resupplied until they reach pre-positioned supplies either in orbit around Mars or on the Martian surface. One of the largest and heaviest resources that the astronauts will need is water. Clean drinking water is not something that can be found or acquired in space. It must be brought along on the journey. To save space and weight, only a limited supply of water can be brought along, and it must be continuously recycled back into the water supply. In the remainder of this activity, students will be given a scenario in which the water supply of their Mars-bound spacecraft is put at risk. It will be up to them to identify the extent of the risk and develop a solution.

### Facilitate the Challenge

#### Meet the Problem

- Ask students if they have ever unexpectedly run out of something important. (Examples: money, gas, their favorite cereal, etc.) What caused them to run out? (Examples: They did not plan properly, they used it at a faster rate than anticipated, they had to use a lot unexpectedly, etc.)
- Explain that even though NASA meticulously plans for all its missions, including emergency scenarios, there are still times when an unexpected situation arises. When astronauts are millions of kilometers from Earth, messages traveling at the speed of light can still take several minutes to reach them. During these times, the crew must take the initiative to troubleshoot the problem.
- Give students the following scenario:

Your team represents the four-member crew of HEM2 (Human Exploration of Mars 2), the second of NASA's manned missions to Mars. You are currently coasting on your 6-month (26-week) journey to the Red Planet. While the crew of HEM1 were the first to land on Mars, they were a smaller crew of three who only stayed on the surface for a few months. You are excited to be part of the first long-term mission, exploring the surface and performing scientific experiments for 18 months. Everything you need has been pre-positioned. There is a logistical supply craft in orbit, containing spare parts, fuel, and supplies for your trip home, as well as a fully stocked outpost on the Martian surface, with everything you will need for your extended stay.

Things have gone smoothly on your mission so far. You have just completed the ninth week of your 26-week journey, and spirits within your spacecraft have been high. Suddenly, there is an alarm. Your water purification system is detecting a major malfunction. After several minutes of troubleshooting, you determine that hydraulic fluid has leaked into your water recycling system and you perform an emergency shutdown to prevent further damage. After repairing the hydraulic line, you restart the water recycling system and assess the damage. Here is what you determine:

### Share With Students



#### Brain Booster

The water purification system currently on use aboard the International Space Station uses a three-step process. First, a filter removes particles and debris. Second, the water is passed through the multifiltration beds that remove organic and inorganic impurities. Finally, the catalytic oxidation reactor kills bacteria and viruses. The recycling of water aboard the space station saves over 18,000 kg of water each year!

Learn more:

[www.nasa.gov/feature/new-brine-processor-increases-water-recycling-on-international-space-station](http://www.nasa.gov/feature/new-brine-processor-increases-water-recycling-on-international-space-station)



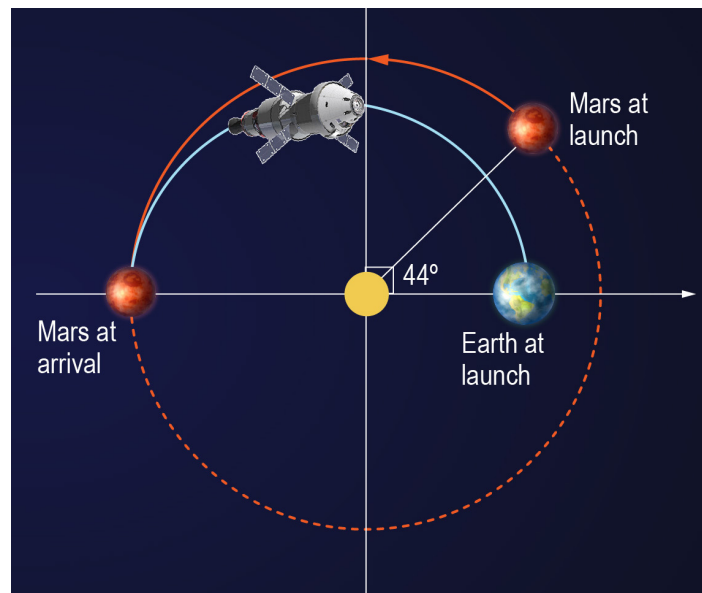
#### On Location

NASA's Marshall Space Flight Center in Huntsville, Alabama, is home to the development of the Environmental Control and Life Support System (ECLSS). This is the system aboard the International Space Station that provides clean air and water for astronauts using the oxygen generation system and the water recovery system. The same technology used in the water recovery system has been adapted to help people around the world have access to clean drinking water by providing water bottle filling stations in remote areas.

Learn more:

[www.nasa.gov/mission\\_pages/station/research/news/b4h-3rd/it-advanced-nasa-water-purification](http://www.nasa.gov/mission_pages/station/research/news/b4h-3rd/it-advanced-nasa-water-purification)

## Hazards to Deep Space Astronauts



- The 20-liter (20-L) tank that feeds the water recycling system has been contaminated with hydraulic fluid, and that water cannot be recovered.
- Due to the emergency shutdown of the water recycling system, the system's memory was erased. You no longer have a record of how much water was originally supplied on the ship or how much clean water remains available. You do, however, have other sources of information about the water recycling system that you have accumulated from various sources. These are detailed in the included Data File.
- The water recycling system is currently operating at an efficiency of 86 percent, well below the designed efficiency of 90 percent.
- The sudden drop in hydraulic pressure caused the communications array to become misaligned. It will take several hours to realign the array, send a message to Earth, and receive a reply.

Since it will be several hours before you receive instructions from NASA, it is up to you to begin working the problem. Do you have enough water to make it to Mars orbit, where you have additional supplies and repair parts waiting? If not, make a specific plan that will ensure your crew will make it to Mars safely.

### Explore Knowns and Unknowns

- Ask students if they understand the purpose of the remainder of the activity. Do they understand what they are trying to accomplish?
- Have students make a list of everything they need to know in order to determine if they have enough water to make it to Mars. Give them time to come up with as much of the list as possible on their own. The list should include the following:
  - How much water did they start with at the beginning of week 1?
  - How much water do they have left at the end of week 9?
  - At what rate are they consuming that water?
  - Will that water run out before the end of their journey (end of week 26)?
  - If the water will run out, what can they do to extend their supply safely?
- Have students make a list of everything that they already know. Give them time to come up with as much of the list as possible on their own. The list should include the following:
  - They are 9 weeks into a 26-week journey.
  - They have already lost 20 L of their water supply.
  - Their damaged water recycling system is currently operating at 86 percent efficiency.

- They have a Data File that contains additional information concerning the water usage and the recycling system.
- Have students use the information they already know and the information they gather from the Data File to answer their questions. Clues and encouragement may be given along the way, but allow them to figure out as much as possible on their own.
- There are two ways to determine how much water was originally aboard the HEM2 ship. Students can use either method depending on their ability level.
  - Easier method: Have students look at the HEM1 water usage graph in their Data File. The beginning of week 1 shows the total amount of water aboard at the beginning of the HEM1 mission, 290 L. This also includes a 50-L emergency supply. Subtract the 50 L; the amount left is the amount of water for needed for a three-person crew: 240 L, or 80 L per crew member. Since HEM2 has a four-person crew and will have the same 50-L emergency supply, the formula to find the original water supply for the HEM2 will be  $\frac{4}{3}(290 \text{ L} - 50 \text{ L}) + 50 \text{ L}$ , or 370 L.
  - Advanced method: Have students look at the excerpt from the Consumable Supply Guide in their Data File. It states that the ship will be packed with the estimated water needed by the crew, based on the water allotted to each astronaut and the efficiency of the water recycling system, plus 50 L of water as an emergency supply. The daily water allotment, taken from the Personnel Manual excerpt in their Data File, states that each astronaut is given a daily allotment of 4.4 L of water. So, each crew member uses 30.8 L of water per week. With a crew of four astronauts aboard HEM2, the total weekly usage would be 123.2 L of water. We know that the average efficiency of the water recycling system is 90 percent, so there is a net loss of 12.3 L of water each week aboard the spaceship. For a 26-week mission, this is a total estimated use of 320 L for the mission. Adding in the 50-L emergency supply brings the total to 370 L.
- To find out how much water they have at the end of week 9, when the accident occurred, students will use the water they started with, 370 L, and subtract the total water consumed/lost. This should all be graphed on the HEM2 water usage graph that they will create. The estimated efficiency of the water recycling system is 90 percent, but by chance, a picture was taken of the water recycling system's display just a few days before the accident. This is shown in the Water System Photo in the students' Data File. The picture shows that the system had been operating at an average efficiency of 91 percent for the first 9 weeks of the mission, before the accident, meaning that only 9 percent of the water used each week was not recovered. So, the net water usage was 0.09 (123.2 L), or 11.1 L per week. This is the rate of water consumption for the first 9 weeks of the mission. This can be graphed week by week, or more advanced students can use the rate as the slope of the line for the first 9 weeks. After 9 weeks, 99.9 L of water should have been used up, giving 270.1 L remaining. Also remember, 20 L of water was permanently lost in the accident due to contamination. This gives us a total of 250.1 L of water remaining after 9 weeks. Student graphs should show a steady slope during the first 9 weeks of the mission, and then a vertical drop, equal to 20 L, at the end of the ninth week.
- After the accident, we know that the water recycling system is operating at an efficiency of only 86 percent. With the consumption rate of 123.2 L of water per week, we now have a new net usage rate of 0.14 (123.2 L) or 17.2 L of water per week. This will be the new consumption rate from the end of week 9 through the remainder of the 26-week journey.
- To determine if they have enough water to complete their journey to Mars, have students use their newly calculated consumption rate of 17.2 L of water per week to graph the water usage from the end of week 9 until the end of week 26. The point on the graph where the line crosses the x-axis will be the point where their crew runs out of water. Have them continue to plot the graph below the x-axis all the way to 26 weeks. The distance below the x-axis at 26 weeks will represent the amount of water the crew will be short in order to complete their journey.
- Have them create a similar graph using the information they have calculated for the HEM2 mission. Have students use this graph to determine when their water supply will run out.

### **Generate Possible Solutions**

- Have students answer the following questions:
  - At current consumption rates, does your crew have enough water to complete the journey to Mars? If not, when will you run out of water?
  - How many additional liters of water would you need to make it safely to Mars?
  - How could you possibly extend your current water supply? Allow students time to come up with their own answers. If they are having trouble, point them to the Personnel Manual excerpt in the Data Files. It breaks down the 4.4-L daily water



## Hazards to Deep Space Astronauts

allotment for each astronaut into the amounts for drinking water, food rehydration, and personal hygiene. Ask students if any of those can be decreased and to what extent.

- Have students brainstorm several plans for how they are going to ration the water. Their plans should be well thought out and include calculations. Remind them that this will begin at week 9 and last until week 26.

### ?? Consider Consequences

- Have students choose their most viable plan and graph it on their HEM2 water usage graphs, beginning at week 9 and using a different color. Remind students that the changes they make must be reasonable and must keep the water supply above zero (the x-axis) all the way to week 26, when they arrive at Mars.
  - Observe students and provide help when needed. They may need guidance on how to use their new water rationing allotment with their calculations.



### Present Findings

- Have each group present their graph to everyone. They should explain what steps they took to reduce crew members' daily water ration and the possible effects those changes would have on the crew. They should also walk through their calculations to illustrate how their new water consumption rates will ensure the water supply will last until the crew reaches Mars.
- After the presentations, ask the following discussion questions:
  - Compare your team's graph with those of other teams. Should all of your graphed lines be the same? **Answer: No**
  - Which one is different? **Answer: The final line from week 9 through week 26**
  - Why? **Answer: Each team created their own new daily consumption rate based on how they cut back on the daily water allotment.**
- Optional: Share students' results on social media using #NextGenSTEM. Be sure to include the module and activity name.

### Extensions

- Have students graph their HEM2 water consumption electronically by creating a data table in a spreadsheet.
- Have students calculate the volume and mass of water needed for their journey if they did not have a water recycling system. Remember, 1 L of water is equal to 1 kg.
- Have students model the volume of water needed for the mission three dimensionally to show how much space it will take up.
- Have students repeat the activity, using a different number of astronauts or a different length journey.

### Reference

Earth, Moon, and Mars Balloons

[www.nasa.gov/audience/foreducators/k-4/features/A\\_Earth\\_Moon\\_Mars\\_Balloons.html](http://www.nasa.gov/audience/foreducators/k-4/features/A_Earth_Moon_Mars_Balloons.html)

## Activity Three: Distance

### Student Handout

In this activity, you will work as a group to create a scale model of the Earth, the Moon, and Mars to illustrate the difference in difficulty between a crewed mission to the Moon and a crewed mission to Mars. You will also determine the amount of water needed for a 6-month mission to Mars and how the water supply will be controlled during the trip.

#### Introduction Activity

- Inflate your Earth balloon to a diameter of 20.0 cm and tie.
- Using your Earth balloon as a reference of scale, inflate your Moon and Mars balloons to the size that you believe they should be. Do not tie the Moon or Mars balloons at this time.
- Using the data in Table 1, calculate the ideal diameter for your Moon and Mars balloon models.
- In this section, round all of your balloon model diameters to the nearest tenth of a centimeter.

Table 1

Body	Diameter, km	Balloon model diameter, cm
Earth	12,756	20.0
Moon	3,476	
Mars	6792	

- To find out the scale of your Earth balloon, divide the actual diameter of the Earth in kilometers (12,756) by the diameter of the balloon model in centimeters (20.0). Round your answer to the nearest whole number.

$$12,756/20.0 = \underline{\hspace{2cm}}$$

- To find the diameters of the other two balloon models, divide the actual diameter by the scale of the models that you just calculated.
- Now inflate the Moon and Mars balloons to the size you calculated in Table 1.
- Model how far away you think the Moon should be from Earth by holding the Moon and Earth balloons apart. Look around the room to compare your Earth-to-Moon distances with those of others.
- Now use the same scale as calculated earlier (638 km in the real world = 1 cm in the scale world) and the information in Table 2 to find the actual distance your Moon balloon needs to be from your Earth balloon. Record this in the top line of Table 2.

Table 2

Bodies	Approximate distance, km	Balloon model distance, cm
Earth to Moon	384,000	
Earth to Mars	78,300,000	



#### Fun Fact

Do astronauts actually drink their own urine? Well, not really. The first step in turning urine back into drinking water is distillation. Urine is made up of mostly water, and in the distillation process, it is heated until the water boils away as steam. The steam is cooled and condensed back into water before going through the remaining steps of the recycling process. So, astronauts do not really drink their own urine; they just drink the water that used to be in their urine.

Learn more:

[www.nasa.gov/centers/marshall/news/releases/2020/nasa-marshall-engineers-refine-hardware-apply-innovative-solutions-to-more-reliably-recycle.html](http://www.nasa.gov/centers/marshall/news/releases/2020/nasa-marshall-engineers-refine-hardware-apply-innovative-solutions-to-more-reliably-recycle.html)



#### Career Corner

Turn your passion for science into a career with NASA. Dr. Jill Williamson's early interest and aptitude in chemistry led to a NASA internship and an eventual career. She is currently the Lead Subsystem Engineer for the Urine Processor Assembly. Watch her interview to learn more about the career path that led her to NASA. Watch the whole series to learn about other NASA STEM Stars!

Learn more:

[youtu.be/dUb\\_NT2JRAE](https://youtu.be/dUb_NT2JRAE)

## Hazards to Deep Space Astronauts

- To find the distance between each of your models, divide the actual approximate distance by the scale of the balloon models.
- Now that you have calculated the correct scale distance between the Earth and Moon, model the distance by holding your Earth and Moon balloons about 6 m apart. This distance represents the distance from the Earth to the Moon that astronauts traveled during the Apollo missions to the Moon during the late 60s and early 70s. They will have to travel that distance again for the Artemis missions to the Moon later in this decade. The trip takes about 3 days each way, or about the same time it takes to drive from the east coast to the west coast of the United States, stopping only to rest.
- Finally, model how far away you think Mars should be from Earth. Look around the room to compare your Earth-to-Mars distances with those of others.
- Complete the second line of Table 2 to find the actual distance apart that your Earth and Mars balloons would have to be in order to be at the proper scale. Can you model it in the room? Could you model it in a hallway? Could you even model it on a football field? Why or why not?

### Challenge

#### ? Meet the Problem

- Have you ever unexpectedly run out of something important? What caused it to run out?
- Even though NASA meticulously plans for all its missions, and even accounts for emergency scenarios, there are still times when an unexpected situation arises. When you are on a spacecraft, millions of kilometers from Earth, messages traveling at the speed of light can still take several minutes to reach you. During these times, it is up to the crew to take the initiative to troubleshoot the problem.
- Here is your team scenario for the remainder of this activity:

Your group represents the four-member crew of HEM2 (Human Exploration of Mars 2), the second of NASA's manned missions to Mars, currently coasting on your 6-month (26-week) journey to the Red Planet. While the crew of HEM1 were the first to land on Mars, they were a smaller crew of three who only stayed on the surface for a few months. You are excited to be part of the first long-term mission, exploring the surface and performing scientific experiments for 18 months. Everything you need has been pre-positioned. There is a logistical supply craft in orbit, containing spare parts, fuel, and supplies for your trip home, as well as a fully stocked outpost on the Martian surface with everything you will need for your extended stay.

Things have gone smoothly on your mission so far. You have just completed week 9 of your 26-week journey, and spirits within your spacecraft have been high. Suddenly, there is an alarm. Your water purification system is detecting a major malfunction. After several minutes of troubleshooting you have determined that hydraulic fluid has leaked into your water recycling system and you perform an emergency shutdown to prevent further damage. After repairing the hydraulic line, you restart the water recycling system and assess the damage. Here is what you determine:

- The 20-liter (20-L) tank that feeds the water recycling system has been contaminated with hydraulic fluid and that water cannot be recovered.
- Due to the emergency shutdown of the water recycling system, the system's memory has been erased. You no longer have a record of how much water was originally supplied on the ship or how much clean water remains available. You do, however, have other sources of information about the water recycling system that you have accumulated from various sources. These are detailed in the included Data File.
- After the accident, the water recycling system is currently operating at an efficiency of 86 percent, well below the designed efficiency of 90 percent.
- The sudden drop in hydraulic pressure caused the communications array to become misaligned. It will take several hours to realign the array, send a message to Earth, and receive a reply.

Since it will be several hours before receiving instructions from NASA, it is up to you to begin working the problem. Do you have enough water to make it to Mars orbit, where you have additional supplies and repair parts waiting? If not, make a specific plan that will ensure your crew will make it to Mars safely.

### Explore Knowns and Unknowns

- Does your team understand what they are attempting to accomplish for remainder of the activity?
- As a team, make a list of everything you need to know in order to determine if you will have enough water to make it to Mars.
- As a team, check off items from your list that you already know.
- Use the information that you already know and any additional information you can gather from the Data File to determine how much water you have left aboard your spacecraft and the rate at which it will be consumed. Use the HEM1 graph as an example to create a graph that shows your water consumption for HEM2.
  - Remember that you have a crew of four aboard HEM2, and HEM1 only had three crew members.
  - Also remember that your graph will change drastically at week 9. You will have a sudden loss of water due to contamination, and your rate of consumption will change due to the damaged water recycling system.
  - Continue to plot the graph to 26 weeks even if you fall below the x-axis.

### Generate Possible Solutions

- Answer the following questions:
  - At current consumption rates, does your crew have enough water to complete the journey to Mars?
  - When will you run out of water?
  - How many additional liters of water would you need to have to make it safely to Mars?
  - How could you possibly extend your current water supply?
- As a team, brainstorm a few plans for how you are going to ration the water.
  - Remember that this will begin at week 9 and last until week 26.
  - Make all the calculations to show that your plans will extend your water supply.

### Consider Consequences

- Choose your most viable plan to extend your water supply. Using a different color, graph it onto your HEM2 water usage graph, beginning at week 9.
  - Remember that the changes you make must be reasonable and must keep the water supply above zero (the x-axis) all the way to week 26, when you arrive at Mars.
  - Make careful calculations to show how your new water rationing plan will change the overall water consumption rate.

### Present Findings

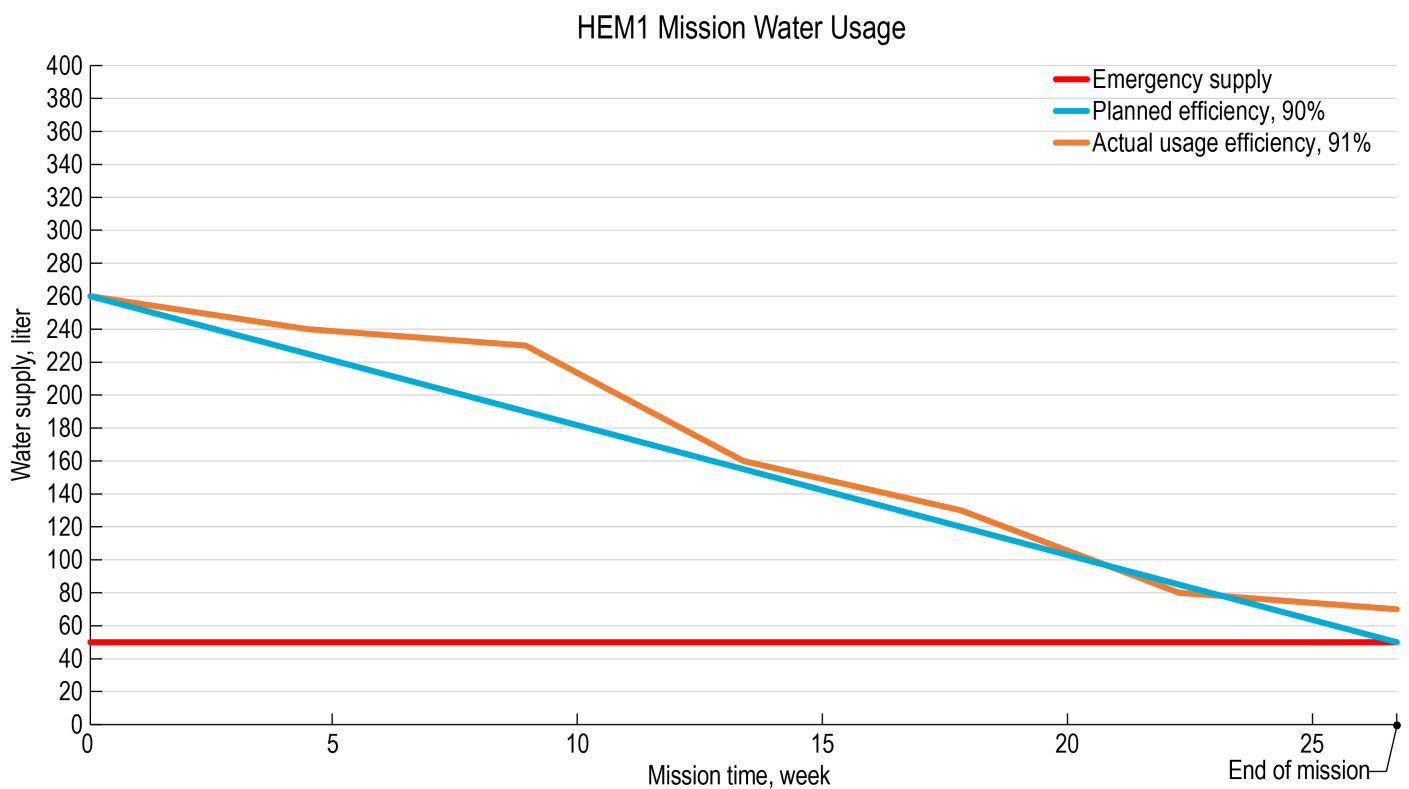
- As a team, prepare to present your HEM2 graph to everyone.
  - Explain what steps you took to reduce the daily ration of water of your crew members and what the possible effects of those changes would be on your crew.
  - Walk through the calculations you made, showing that the new water consumption rate ensures that the water supply will last until your crew reaches Mars.
- After your presentation, you will be asked the following questions:
  - Compare your team's graph to those of other teams. Should all your graphed lines be the same as theirs?
  - Which one is different?
  - Why?

# Data File

After the loss of the water recycling system's memory, your crew rounded up as much information about the water recycling system as they could from various sources aboard your spacecraft. Here are five items you have put together that contain useful information:

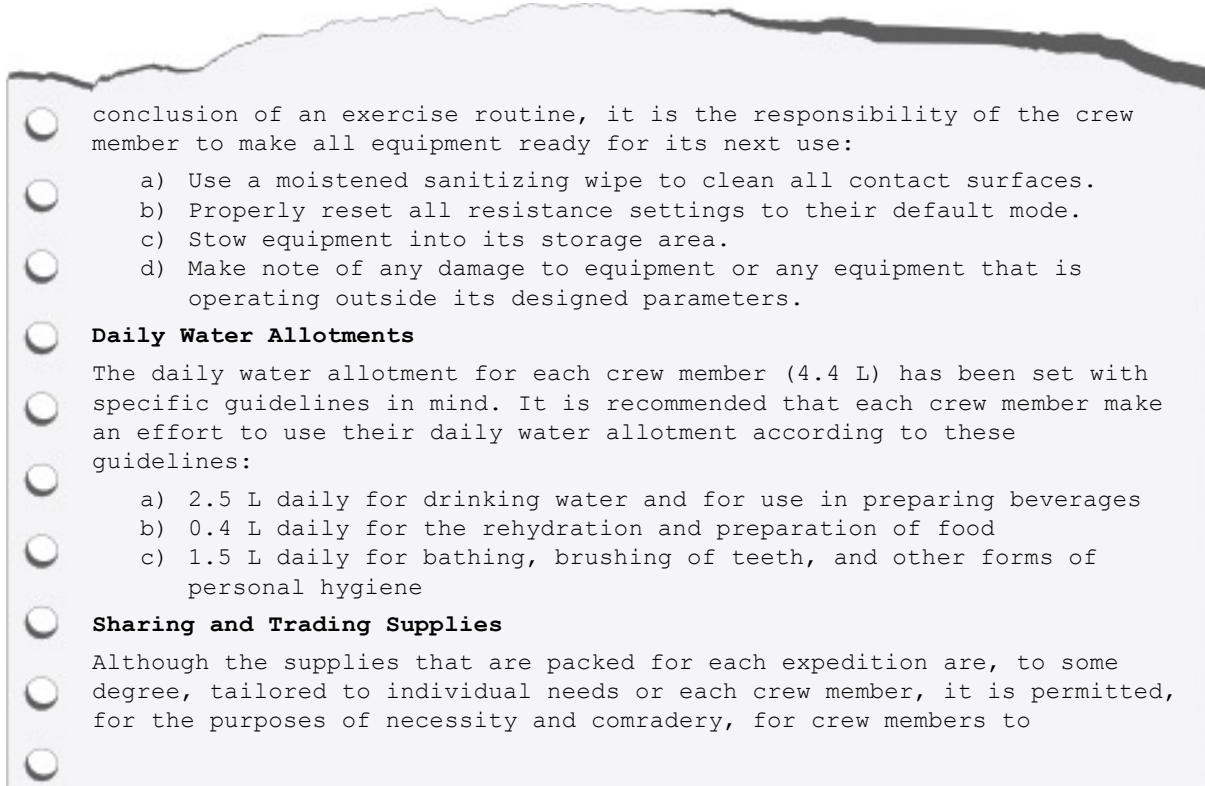
1. HEM1 Mission Water Usage Graph: This graph was found in one of your training manuals and depicts the actual water consumption rates of the HEM1 expedition.
2. Personnel Guide Excerpt: This page from your crew personnel guide shows various rules and regulations for the mission, including how much water allotment each astronaut receives.
3. Consumable Supply Guide Excerpt: This page from the consumable supply guide shows regulations regarding how the amounts of various consumables are chosen for the mission.
4. Crew Member Photo: This casual photo of one of your crew members was taken just days before the malfunction. The display of the water recycling system can be seen in the photo, showing the system's overall average efficiency thus far on the mission.
5. Note Pad: Depicts a few important things your crew remembers jotted down from their training about the water recycling system and about the emergency as well as some important questions that will be helpful to answer.

## HEM1 Mission Water Usage Graph

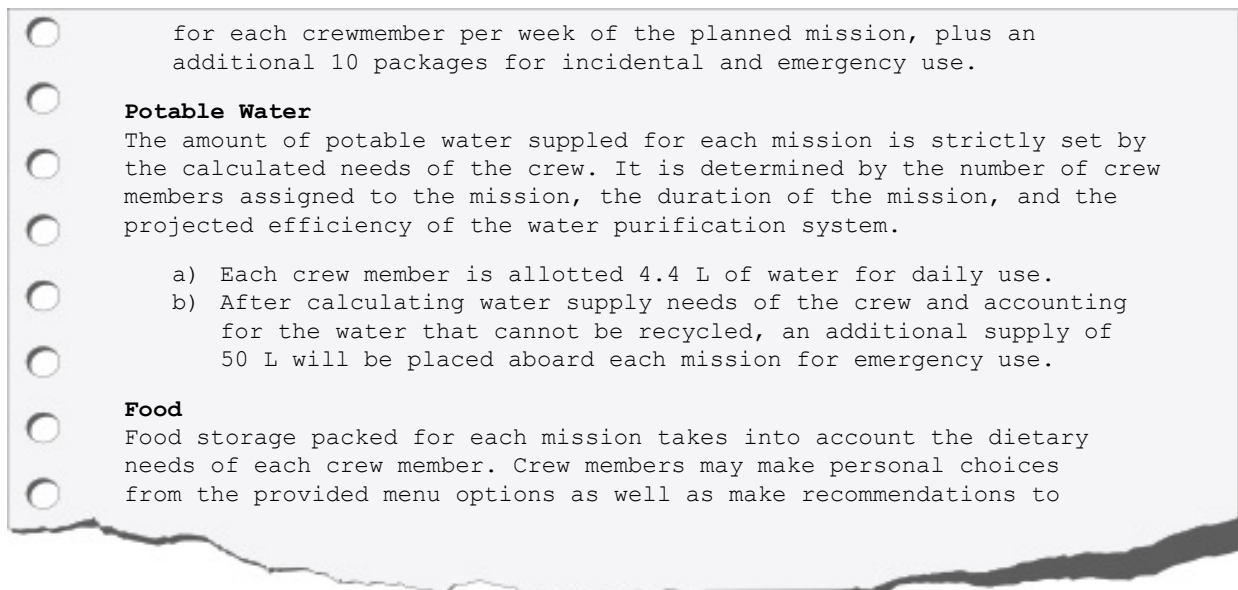




## Personnel Guide Excerpt



## Consumable Supply Guide Excerpt



## Crew Member Photo



## Note Pad

- EXPECTED EFFICIENCY OF 90%
- 20 LITERS OF WATER LOST, NEW EFFICIENCY OF 86%
- HOW MUCH WATER DID WE START WITH?
- HOW MUCH WATER LEFT?

# Activity Four: Gravity

## Educator Notes

Students will

- Identify the challenges microgravity poses to the bones and muscles of astronauts in space.
- Determine the fracture threshold of fictitious astronauts.
- Create a design concept for a functional compact exercise device for potential use by NASA.
- Calculate the amount of work being completed by determining force and distance.

### Challenge Overview

Students are asked to design a functional exercise device that will help mitigate bone loss and atrophy during spaceflight. Students will use their knowledge of the skeletal system, osteoporosis, and the current exercise equipment on the International Space Station to design a new compact exercise device that is compatible with the spaceflight environment. Students will also create a hypothetical presentation for NASA.

### Suggested Pacing

90 to 180 minutes

### National STEM Standards

Science and Engineering (NGSS)	
<p><i>Disciplinary Core Ideas</i></p> <ul style="list-style-type: none"> <li>• MS-LS1.A: All living things are made up of cells, which is the smallest unit that can be said to be alive. An organism may consist of one single cell (unicellular) or many different numbers and types of cells (multicellular).</li> <li>• MS-PS3-2: Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.</li> <li>• 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.</li> </ul> <p><i>Crosscutting Concepts</i></p> <ul style="list-style-type: none"> <li>• Systems may interact with other systems; they may have subsystems and be part of larger complex systems.</li> </ul>	<p><i>Science and Engineering Practices</i></p> <ul style="list-style-type: none"> <li>• Asking Questions and Defining Problems: A practice of science is to ask and refine questions that lead to descriptions and explanations of how the natural and designed world works and which can be empirically tested.</li> <li>• Constructing Explanations and Designing Solutions: The products of science are explanations, and the products of engineering are solutions.</li> <li>• Obtaining, Evaluating, and Communicating Information: Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical and professional activity.</li> </ul>
Technology (ISTE)	
<p><i>Standards for Students</i></p> <ul style="list-style-type: none"> <li>• Creative Communicator: Students communicate clearly and express themselves creatively for a variety of purposes using the platforms, tools, styles, formats, and digital media appropriate for their goals.</li> </ul>	<p><i>Standards for Students</i></p> <ul style="list-style-type: none"> <li>• Knowledge Constructor 3d: Students build knowledge by actively exploring real-world issues and problems, developing ideas and theories, and pursuing answers and solutions.</li> </ul>
Mathematics (CCSS)	
<p><i>Mathematical Practices</i></p> <ul style="list-style-type: none"> <li>• CCSS.MATH.CONTENT.6.EE.A.2: Write, read, and evaluate expressions in which letters stand for numbers.</li> <li>• CCSS.MATH.CONTENT.7.EE.B.3: Solve multistep real-life and mathematical problems posed with positive and negative rational numbers in any form (whole numbers, fractions,</li> </ul>	<p><i>Mathematical Practices (continued)</i></p> <ul style="list-style-type: none"> <li>and decimals), using tools strategically. Apply properties of operations to calculate with numbers in any form, convert between forms as appropriate, and assess the reasonableness of answers using mental computation and estimation strategies.</li> </ul>

### Challenge Preparation

The educator should

- Read the introduction and background information and Educator Notes.
- Review the worksheets: Bone Mass of an Astronaut, More Work!, Astronaut in Motion, and Exercise Equipment on the International Space Station.
- Make copies of the worksheets for each student.
- If students will be building their own device, assemble materials or provide a list of materials they can use. (Educators may opt to have students submit only their design.)
- Have videos preloaded for presentation.

## Hazards to Deep Space Astronauts

Optional: This activity can be done as an interdisciplinary activity with the physical education department or a health department.

### Handouts

- Bone Mass of an Astronaut (one copy for each student)
- Exercise Equipment on the International Space Station (one copy per team)
- More Work! (It is recommended that students complete this individually.)
- Astronaut in Motion (It is recommended that students complete this individually.)
- Scratch paper

### Suggested Materials (if students are building their design)

- Bicycle tubing or surgical tubing
- Cardboard
- Cloth (dishrags, cotton fabric that stretches, etc.)
- Elastic cord (e.g., bungee cord)
- Glue or tape
- Goggles and face shield (The student doing the testing of the device may need safety glasses and/or face shield.)
- Hole puncher
- Rubberbands
- Springs (limit the strength and size of the springs; refer to the safety tip below)
- Paper cups
- Scissors
- String
- Wooden dowels

Note: This is a suggested list. Students could also have a scavenger hunt and use readily available materials.

### Safety

- Limit the strength and size of the spring.
- To prevent accidental release, discharge, or injury, handle with extreme caution.
- Eye and face protection must always be worn during construction and testing.
- Always direct a sharp edge away from yourself and others.
- Before using scissors, discuss safety issues surrounding proper use of the equipment.
- Ensure that students' device does not contain sharp or pointed surfaces.
- Ensure that the device is sturdy and functional.
- Use caution when students are demonstrating the device.
- Allow for a testing area free of obstruction or hazards.
- Have other students stand back for testing.

### Introduce the Challenge

- Provide context for the activity using the introduction and background information in this guide.
- Optional: Prepare for discussion by sharing the following video: "When You Land, Can You Stand?" [www.nasa.gov/content/when-you-land-can-you-stand-one-year-mission-video-miniseries-functional-performance](http://www.nasa.gov/content/when-you-land-can-you-stand-one-year-mission-video-miniseries-functional-performance)
- Ask students, "Can astronauts walk after spaceflight?" Have them explain why or why not.
- Have students do a simple exercise like jumping jacks until they get fatigued. Discuss whether they think they would be able to do the same exercise in deep space.

- Discuss what gravity is and how living in different gravitational fields can affect the body.
- Explain that our knowledge about gravity’s effects on the body in deep space is limited because research has been limited to low Earth orbit.
- Have students complete the Astronaut in Motion worksheet to review the skeletal system.

**Astronaut in Motion Worksheet Answer Key:**

**1. Cranium (skull). 2. Vertebrae. 3. Clavicle (collarbone). 4. Sternum. 5. Ribs. 6. Humerus. 7. Ulna. 8. Radius. 9. Pelvis (hip bones). 10. Carpals (wrist bones). 11. Metacarpals (hand bones). 12. Phalanges (finger bones). 13. Femur. 14. Patella (kneecap). 15. Fibula. 16. Tibia (shinbone). 17. Tarsals. 18. Metatarsals (foot bones). 19. Phalanges (toe bones).**

- If students need additional scaffolding, they can create a graphic organizer (concept map, spider chart, or KWL chart) that reviews the following skeletal system vocabulary: bones, cells, vertebrae, skull, ribs, pelvis, femur, humerus, joint, ligament, and cartilage.
- Refer to the background information and discuss with students why bone and muscle loss occurs in the lower body. Discuss how exercise will help retain bone and muscle mass. Remind students that astronauts no longer use their bones and muscles to help support their bodies while standing and walking, because they float in space.
  - Students can read Bone and Muscle Loss in Microgravity (see Resources) to better understand why the lower body is affected (no weight load on the lower body in space).
- Review with students the concept of work and force. Review the equation of work: **Work = Force × Distance**. For example, if a person pushes a cart up a hill using a force of 500 Newtons and the box is pushed 6 meters, the work will be 3,000 Joules.
 

Note: Students will be using the work equation for the More Work! worksheet during the Improve phase of the challenge.
- Have students complete the Bone Mass of an Astronaut worksheet individually and discuss their findings as a team.
 

Note: If students struggle, this worksheet can be completed in teams or in a whole-group setting.
- Explain the role of engineers in designing technology to solve problems. Share the NASA video “Intro to Engineering” ([www.youtube.com/watch?v=wE-z\\_TJyzil](http://www.youtube.com/watch?v=wE-z_TJyzil)) and introduce the engineering design process.
- Divide students into teams of three to four. Consider assigning roles and tasks to individual students within the group. See the Teamwork section at the beginning of the guide for suggestions. Distribute the handouts and scratch paper.
- Explain the challenge to students:
  - The goal is to design a concept plan and build a functional device that exercises the body to prevent bone loss and muscle atrophy while also being compact enough for an astronaut to use on a deep space mission. Each team will create a design concept for their exercise device based on the gravitational field where the device will be used. Students will decide if their functional compact device will be used on the surface of the Moon (1/6 of Earth’s gravity), in transit to the Moon or Mars (zero gravity), on the surface on Mars (3/8 of Earth’s gravity), or in all three gravity environments.
  - Use the suggested materials list to inform students what materials are available or provide the materials for teams to build a prototype of their exercise device.
  - The device must be sturdy enough for the student to demonstrate the device during the presentation.
  - Each team will present their device and explain how it can mitigate bone loss and muscle atrophy.
- Review the following criteria and constraints of the activity with students:

Criteria	Constraints
Exercise device must be functional to strengthen the lower-body skeletal region (femur, pelvis, and hip).	You may only use everyday, readily available supplies.
Exercise device must be compact, with a maximum height of 42.4 cm, a maximum width of 33 cm, and a maximum diameter of 21.6 cm (size of a book bag or standard shoebox).	You may not use any type of free weights.
Total force of the device must be no less than 3 kg and no more than 13 kg.	
Prototype must operate for a minimum of 1 minute.	

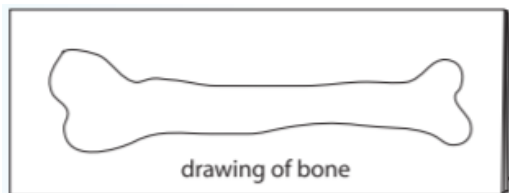


## Hazards to Deep Space Astronauts

### Facilitate the Challenge

#### ? Ask

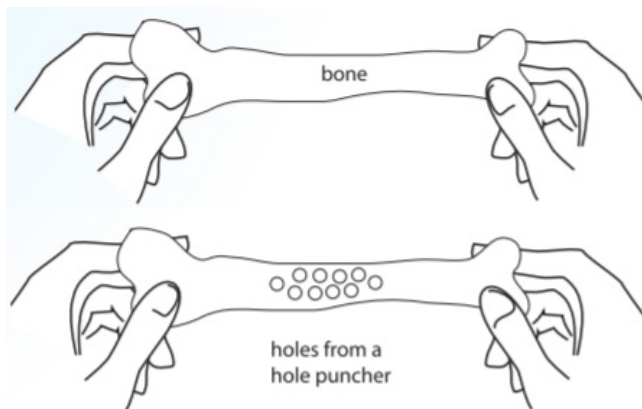
- Choose one or more of the following clips to share with students:
  - NASA Hazards of Human Spaceflight: Hazard 4: Gravity Fields (3:05). [www.youtube.com/watch?v=f3-96ZbY5NA](http://www.youtube.com/watch?v=f3-96ZbY5NA)
  - Growing Bones in Space. (1:51) [www.youtube.com/watch?v=ht9zTT4qPel](http://www.youtube.com/watch?v=ht9zTT4qPel)
  - STEMonstrations: Exercise. (2:43) [www.nasa.gov/stemonstrations-exercise.html](http://www.nasa.gov/stemonstrations-exercise.html)
- After the clips, engage in a discussion with students using the following questions:
  - What challenges caused by gravity do astronauts encounter?
  - How would you compare bone density loss on Earth to bone density loss by astronauts in space?
  - Why is bone density loss research so important to people on Earth?
  - How would you prevent bone and muscle loss in space?
- Complete the following demonstration with students to understand the problems associated with bone loss.
  - Take a piece of paper and fold it in half.
  - Draw a picture of the femur on one half of the sheet. Cut out the picture so there are now two bones.



- Activate prior knowledge by asking students questions about bones. For example, what makes up bone? In what body system would you find bones? Why are bones hard?

Note: Emphasize the fact that bones are made of cells and explain how the structure dictates its function.

- Tug at the first paper bone, or have a student tug at it, to see how many tugs it takes to tear the paper. Use a hole puncher to create 10 holes in the second bone. Now tug at second bone to see how long it takes to tear.



- Ask students what happened to the bone after bone density loss.

### Share With Students



#### Brain Booster

Did you know that astronaut Scott Kelly has a twin? Scott and his twin brother, Mark, participated in a twin study to investigate how microgravity affects different aspects of the body. Scott was in space and Mark was on Earth. This was a unique study because twins share the same genetic makeup, so they are physically similar. The Twins Study was a 340-day investigation conducted by NASA's Human Research Program. Find out how NASA used 10 billion miles of DNA to investigate nurture versus nature.

Learn more:

[www.nasa.gov/twins-study/fun-facts-and-shareables](http://www.nasa.gov/twins-study/fun-facts-and-shareables)



#### On Location

Have you ever wondered how NASA researches microgravity? The Zero Gravity Research Facility at Glenn Research Center has a chamber with a 467-foot (142-meter) drop that creates a microgravity environment. Take a tour of the facility using the link below.

Learn more:

[www.nasa.gov/specials/zero-g/](http://www.nasa.gov/specials/zero-g/)

### Imagine

- Have students research the gravitational fields that astronauts will experience during the different phases of a spaceflight mission.
  - Mars Exploration Program. [mars.nasa.gov/all-about-mars/facts/](https://mars.nasa.gov/all-about-mars/facts/)
  - Astronaut Begins “Boston Marathon” in Space. (0:59) [www.youtube.com/watch?v=nDCdDybegVc](https://www.youtube.com/watch?v=nDCdDybegVc)
- Ensure that each team examines the three types of exercise equipment pictured in the handout Exercise Equipment on the International Space Station.
- Ask students to individually sketch their exercise device concept. Remind them about the criteria and constraints.
- After students have drawn their individual sketches, allow students time to examine the available materials.
- Have students work in their teams to brainstorm how the materials can be used to create a team design that takes into account the location where the device will be used—whether in transit, on the lunar surface, on the surface of Mars, or in all three gravitational fields.

### Plan

- Have teams sketch a design for their exercise device. Note: Each design must incorporate at least one design idea from each member.
- Have students label each part with its function and explain how they optimized their design for the spaceflight environment (e.g., using lightweight materials, being aware of potential hazards to the astronauts, avoiding loose parts, etc.).

### Create

- Have each team construct their exercise device.
- Have teams measure the dimensions of their exercise device to ensure it will fit into a book bag or standard shoebox.
- Ensure that there are no edges that will cause harm as students test their device.

### Test

- Have at least two members of each team test the exercise device to make sure it is functional.
- The device must be functional to complete repetitions for at least 1 minute.
- Ensure that the device does not cause any safety concerns (loose cords, springs, etc.). Also, students must remember that everything in space floats, so small parts may be an issue.

### Improve

- Have each team identify two areas in which their device could be improved.
- Allow each team additional time and materials to incorporate changes to their device.
- Have at least two team members use the device for at least 1 minute. Try to choose students who did not perform the first test.
- Have students complete the More Work! worksheet.

### Share

- Have students present their device to everyone using a format designated by the educator. Examples: a commercial, a slide presentation, or an advertisement.
- Engage students with the following discussion questions:
  - How can your device create resistance? Why is that so important in strengthening muscles?
  - Identify what gravitational field your device is better suited for and explain why.
  - What ways could your device be adapted to enable it to work better in different gravitational fields?
  - What flaws did your team identify in the first design? How were these improved?

## Hazards to Deep Space Astronauts

- If you could have all the materials you needed, how could you optimize your design to make it as small and lightweight as possible? Are there other materials that are lighter that could be used?
- Optional: Share students' results on social media using #NextGenSTEM. Be sure to include the module and activity name.

### Extensions

- If supplies are not available, or not feasible, students can just create a concept design (sketch) and present their design.
- Students can use a force plate to demonstrate how much force is being exerted.
- “Get a Leg Up” activity allows students to simulate the fluid shift experienced by astronauts upon entering space. [www.nasa.gov/stem-ed-resources/get-a-leg-up-activity.html](http://www.nasa.gov/stem-ed-resources/get-a-leg-up-activity.html)
- “Bendy Bones” allows students to see the effect of calcium in building and maintaining strong bones by comparing bone before and after it is introduced to vinegar. [www.nasa.gov/sites/default/files/heo-cpfc-bendy\\_bones\\_seg2.pdf](http://www.nasa.gov/sites/default/files/heo-cpfc-bendy_bones_seg2.pdf)

### References

Hole-y Bones. [www.nasa.gov/pdf/663095main\\_Hole-y\\_Bones\\_Activity.pdf](http://www.nasa.gov/pdf/663095main_Hole-y_Bones_Activity.pdf)

Bag of Bones. [www.nasa.gov/pdf/663094main\\_Bag\\_of\\_Bones\\_Activity.pdf](http://www.nasa.gov/pdf/663094main_Bag_of_Bones_Activity.pdf)

### Resources

The Human Body in Space. [www.nasa.gov/hrp/bodyinspace](http://www.nasa.gov/hrp/bodyinspace)

Bone and Muscle Loss in Microgravity. [www.nasa.gov/mission\\_pages/station/research/station-science-101/bone-muscle-loss-in-microgravity/#:~:text=In%20the%20microgravity%20environment%20aboard,during%20their%20stays%20in%20space](http://www.nasa.gov/mission_pages/station/research/station-science-101/bone-muscle-loss-in-microgravity/#:~:text=In%20the%20microgravity%20environment%20aboard,during%20their%20stays%20in%20space).

Houston, We Have a Podcast: Hazard 4: Gravity. [www.nasa.gov/johnson/HWHAP/hazard-4-gravity](http://www.nasa.gov/johnson/HWHAP/hazard-4-gravity)

Exercise Countermeasures Lab at NASA Glenn (video). [www.youtube.com/watch?v=W8G07FG1g8I](http://www.youtube.com/watch?v=W8G07FG1g8I)

Microgravity Educator Guide. [www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Microgravity\\_Teachers\\_Guide.html](http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Microgravity_Teachers_Guide.html)

## Activity Four: Gravity

### Student Handout

#### Your Challenge

You will design a functional exercise device that will help mitigate the damage of bone loss and atrophy. You will use your knowledge of the skeletal system, osteoporosis, and the current exercise equipment on the International Space Station to design a new exercise device that is compatible with the spaceflight environment (i.e., compact). You will also create a presentation designed to show NASA the benefits of the device.

Criteria	Constraints
Exercise device must be functional to strengthen the lower-body skeletal region (femur, pelvis, and hip).	You may only use everyday, readily available supplies.
Exercise device must be compact, with a maximum height of 42.4 cm, a maximum width of 33 cm, and a maximum diameter of 21.6 cm (the size of a book bag or standard shoebox).	You may not use any type of free weights.
Total force of the device must be no less than 3 kg and no more than 13 kg.	
Prototype must operate for a minimum of 1 minute.	

#### ? Ask

- Discuss the following questions after viewing the video clips that will be shown to you:
  - What challenges caused by gravity do astronauts encounter?
  - How would you compare bone density loss on Earth to bone density loss by astronauts in space?
  - Why is bone density loss research so important to people on Earth?
  - How would you prevent bone and muscle loss in space?
- Complete the Bone Mass of an Astronaut worksheet.

#### 💡 Imagine

- Examine the three types of exercise equipment used on the International Space Station using the pictures provided. Compare and contrast the similarities and differences of each machine. How can these machines help strengthen the lower body?
- Research the three gravitational fields (Moon, in transit, and Mars) that astronauts will experience as they travel in deep space. How will the gravitational fields affect the way astronauts exercise? Why is it important for the exercise device to strengthen the lower body?
- Use the discussion to decide what gravitational field(s) your device is best suited for. Also, think about what kind of exercise the device offers. Aerobic? Weight training or resistive? Combination?
- Sketch a design of what your exercise device will look like.
- Examine the building materials or the list of materials available to your team. Brainstorm with your team how the materials can be used in your device.

#### Fun Fact

Did you know that researchers use mice to research the effects of microgravity in astronauts? There may be a protein that can help build muscle and prevent bone loss. Researchers sent 40 mice to live in the International Space Station and studied 40 other mice here on Earth. They hope their Mighty Mice and these proteins can benefit astronauts in space.

Learn more:

[www.nasa.gov/mission\\_pages/station/research/news/rodents-and-a-rocket-carried-researchers-dreams-into-space-rodent-research-19](http://www.nasa.gov/mission_pages/station/research/news/rodents-and-a-rocket-carried-researchers-dreams-into-space-rodent-research-19)

#### Career Corner

An exercise physiologist analyzes patients' fitness to help them improve their health or maintain good health. This is exactly what an exercise physiologist does at NASA, but these scientists are improving astronaut health and helping to find solutions to the health problems astronauts may develop in deep space.

Learn more:

[www.nasa.gov/hhp/physiology](http://www.nasa.gov/hhp/physiology)

## Hazards to Deep Space Astronauts

### Plan

- As a team, sketch a design of your exercise device. Your sketch must include at least one design idea from each team member.
- Label each major part with its name and purpose and note how you optimized your design for the spaceflight environment.
- Be sure to explain how your device is uniquely designed for the gravitational field your team chose.

### Create (Only if you are building your device—if you are not building the device, go to the **Share** phase.)

- Construct your exercise device if your instructor has asked for a prototype.
- Use safety glasses with face shields while handling or extending springs, elastic, cords, tubing, or rubberbands. Use extreme caution to ensure that any sudden release of energy will be directed away from you and others.
- Measure the dimensions of the exercise device to ensure that it meets the design criteria.
- Ensure that there are no pinch points or edges that will cause harm.

### Test (Only if you are building your device—if you are not building the device, go to the **Share** phase.)

- If you have built your design, have at least two members of the team test the exercise device to make sure it is functional.
- The team members testing must use safety glasses with face shields while testing. All others in the area must do the same.
- The exercise device must be functional to complete at least 10 repetitions.
- Ensure that the device does not cause any safety hazards (sharp ends, pinch points, sudden release of energy from loose ends, springs, elastic tubing, etc.). Also, remember that everything in space floats, so small parts may be an issue.

### Improve (Only if you are building your device—if you are not building the device, go to the **Share** phase.)

- Identify two areas in which the device could be improved.
- Incorporate the changes to your device.
- Have at least two team members (different from the first test) use the device for at least 1 minute.
- Each team member will complete the More Work! worksheet.

### Share

- You will present the device to everyone using a designated format.
- Discuss the following questions as a team:
  - How can your device create resistance? Why is that so important in strengthening muscles?
  - Identify what gravitational field(s) your device is better suited for and explain why.
  - What ways could your device be adapted to enable it to work better in different gravitational fields?
  - What flaws did your team identify in the first design? How were these improved?
  - If you could have all the materials you needed, how could you optimize your design to make it as small and lightweight as possible? Are there other materials that are lighter that could be used?



# Astronaut in Motion Worksheet

Astronauts need to exercise to keep their bones strong.

Every astronaut is made up of 206 bones. Bones give the body structure, protect organs, and much more.

The skull (**cranium**) protects the most important part of all, the brain. The cranium is connected to the **vertebrae** that form the back. The heart, lungs, and liver are protected by **ribs**. There are 12 sets of ribs that run from the backbone to the **sternum** (a strong bone in the center of the chest that holds the ribs in place).

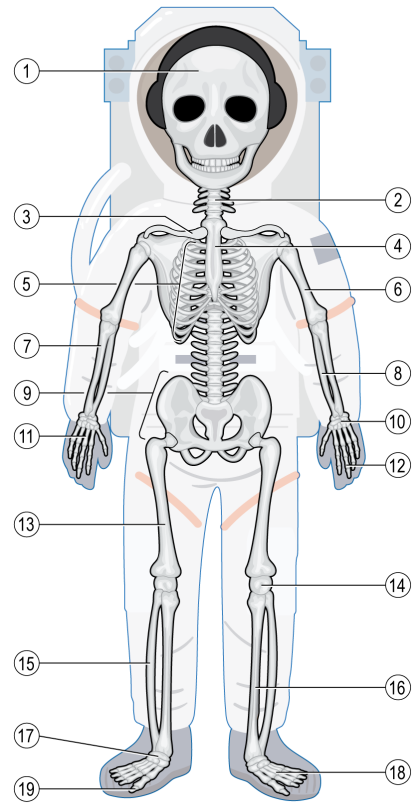
The collarbone (**clavicle**) has a **humerus**, which makes up part of the shoulder bone. Below the elbow, you have the **radius** and **ulna**. So how can you tell which is which? The **radius** is on the thumb side and the **ulna** is on the “pinky side.” The hand is built in 3 sections: **phalanges (fingers)**, **metacarpals**, and **carpals**.

The thighbone is the **femur**, and it connects to the **pelvis** (hip bones) and the knee. Why is the knee important? The knee is the biggest joint in the body, and it allows the leg to straighten and bend, so it needs to be protected. The kneecap (**patella**) protects the front of the knee.

Below the knee are two bones: the **tibia** and the **fibula**. The **tibia** (shinbone) is the larger bone and connects the knee and anklebone. The **fibula** supports a significant amount of the astronaut’s body weight—but remember, this does not happen in space.

A quarter of an astronaut’s bones are found in the feet. There are 52 bones in the foot. The feet have **tarsals** (anklebones), **metatarsals** (five long bones in the middle of the foot), and more **phalanges** (toes).

So how does an astronaut move? Bones meet at the joints that connect muscles and bones. Joints hold the skeleton together and allow movement. Muscles work by voluntarily contracting to make bones move. The bones, muscles, and joints all work together to get the astronaut moving—even in space.

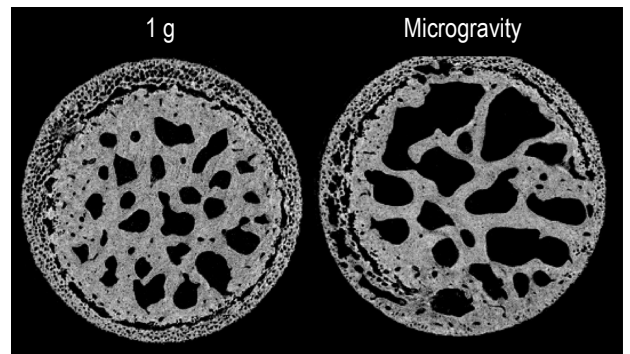


1. \_\_\_\_\_
2. \_\_\_\_\_
3. \_\_\_\_\_
4. \_\_\_\_\_

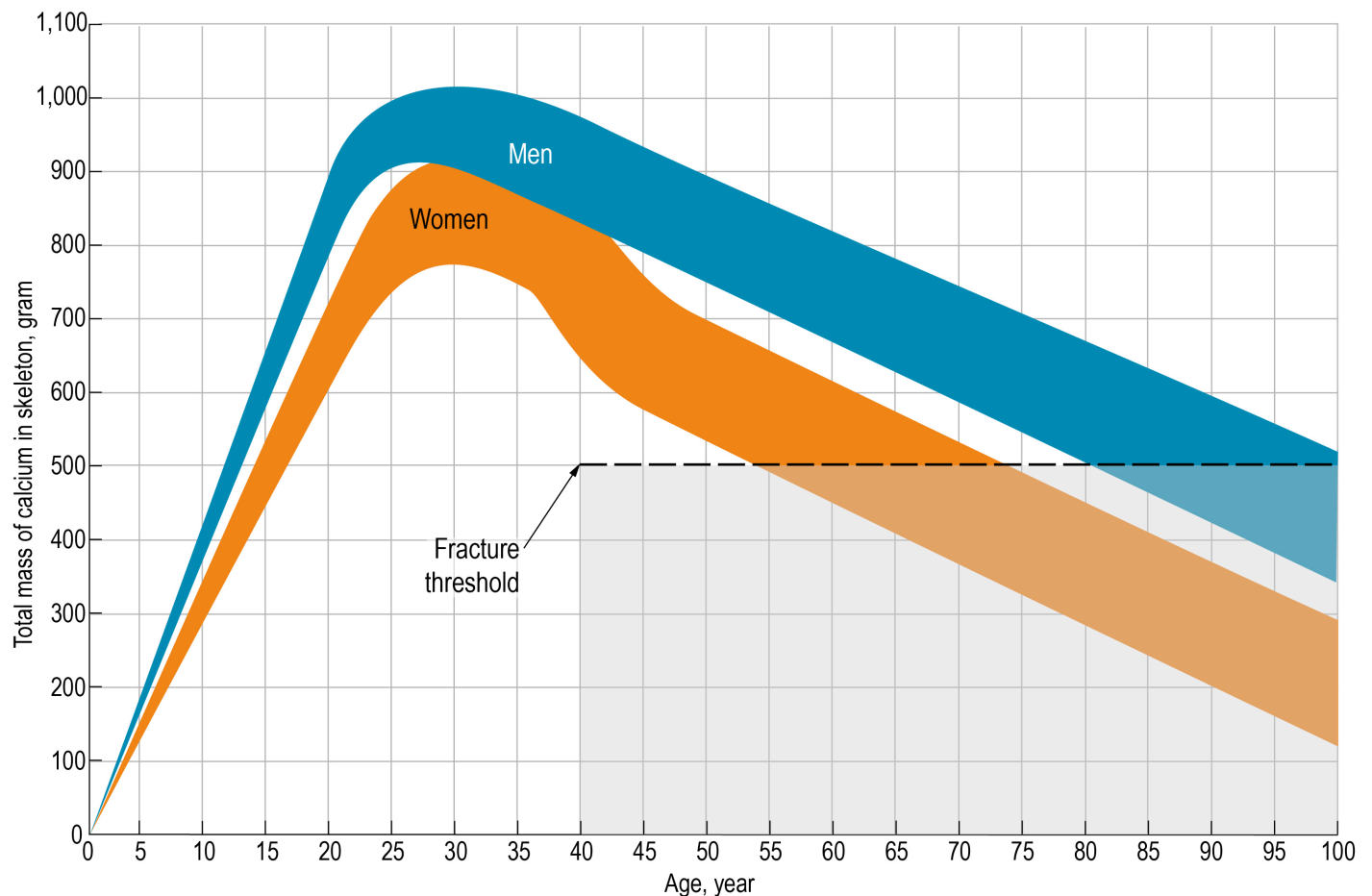
5. \_\_\_\_\_
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18. \_\_\_\_\_
19. \_\_\_\_\_

## Bone Mass of an Astronaut

Breaking a bone is a fairly common injury, but with modern medicine, a broken bone is usually little more than a painful inconvenience. Unfortunately, astronauts might not always have a doctor with them (isolation), and the nearest hospital is millions of miles away (distance). To make matters worse, the surfaces of the Moon and Mars are rough and full of tripping hazards (environment). Perhaps worst of all, as far as broken bones go, is that the reduced exposure to the force of gravity during spaceflight will cause loss of bone mass, as shown in the cross sections to the right.



Just as a skinny twig is easier to break than a thick branch, the less mass an astronaut's bones have, the easier they are to break. Some bone loss is natural with age, as shown in the graph below. The width of each band shows the typical range of bone mass for each sex at each age.



In microgravity, bone mineral loss occurs more rapidly because the bones do not need to resist the force of Earth's gravity. This bone loss occurs at an average rate of approximately 1 percent per month. We do not yet know if fractional gravity, present on the Moon and Mars, will be enough to reduce or prevent that bone loss. In the graph above, the line marked "fracture threshold" separates what doctors consider to be normal risk for breaking a bone versus high risk for breaking a bone.

**Directions:** Complete the table below to track bone mass loss for each of eight hypothetical astronauts on a mission to Mars. For the purposes of this activity, the fracture threshold for anyone old enough to be an astronaut is considered to be 500 grams of bone mass. Also, we will assume that people lose just as much bone mass in fractional gravity as they do in microgravity (although NASA does not yet know if that is actually the case).

**Example:**

- An astronaut with an initial bone mass of 510 grams (g) will lose an average of 1 percent of their bone mass in the first month.
- Since 1 percent of 510 g is 5.1 g (compute  $0.01 \times 510$  g to get this), this astronaut would have 504.9 g of bone mass (compute  $510 - 5.1$  g to get this) after the first month.
- A faster way to do this calculation is to realize that if you lose 1 percent of bone mass, you have 99 percent left. So, after the second month, this astronaut would have 499.85 g of bone mass (compute  $0.99 \times 504.9$  g to get this).
- This astronaut would be at high risk of breaking a bone in as little as 2 months of spaceflight! A fall that would have caused little more than a bruise on Earth might result in a broken bone by the time the astronaut lands on Mars, let alone by the time they return back to Earth.

Initial bone mass, g	Bone mass after 1 month	Bone mass after 6 months (approximate travel to Mars)	Bone mass after 9 months (after 3 month stay on Mars)	Bone mass after 15 months (approximate return to Earth)	Does the astronaut ever have high risk of bone breaks? Starting when?
1,000					
950					
910					
865					
812					
739					
621					
567					

**Extension questions:**

1. Does an astronaut lose as much bone mass in the 1st month as in the 2nd month? What about the 15th month? Why?
2. If you plot the bone mass of each astronaut over time on a scatterplot, does the pattern follow a straight line?
3. How many months could the typical 40-year-old man or woman survive in reduced gravity without becoming at high risk of bone breaks?
4. A person with more initial bone mass can withstand the effects of reduced gravity longer without high risk of breaks. Should NASA hire only people with high initial bone mass? Why or why not?
5. How might the above table change if the fractional gravity of Mars slowed bone loss to just 0.5 percent per month? What if astronauts stayed an entire year on Mars instead of just 3 months?

# Exercise Equipment on the International Space Station

## T2 Treadmill



[www.nasa.gov/image-feature/exercising-on-the-t2-treadmill](http://www.nasa.gov/image-feature/exercising-on-the-t2-treadmill)

## Advanced Resistive Exercise Device (ARED)



[www.nasa.gov/content/chris-cassidy-exercises-on-the-ared](http://www.nasa.gov/content/chris-cassidy-exercises-on-the-ared)



## Cycle Ergometer With Vibration Isolation System (CEVIS)



[www.nasa.gov/content/steve-swanson-works-out-on-the-cevis](http://www.nasa.gov/content/steve-swanson-works-out-on-the-cevis)



# More Work!

Each time you exercise, you are doing work. The work you do is equal to the force you exert multiplied by the distance you exert the force ( $\text{Work} = \text{Force} \times \text{Distance}$ ). In this activity, you will use distances, forces, and times in order to calculate the work of your muscles. Remember that one of the problems with microgravity is that astronauts lose up to 20 percent of muscle mass on spaceflights lasting 5 to 11 days.

## Directions

1. Find a clear area free of obstructions and hazards. Others should keep distance while you exercise. Use safety glasses and a face shield.
2. Using your team exercise device, perform your exercise for 1 minute to determine force and distance.
  - Estimate the force that you are exerting. Hint: At the surface of the Earth, 1 pound = 4.45 newtons (approximately).
  - Have a team member measure the distance that you exerted the force.
  - Enter your measurements on your own data table.
3. Now, perform several repetitions using your exercise device for at least 1 minute.
4. Calculate total work done for each team member who uses the exercise device.

## Calculations

As an example, suppose your teammate weighs about 130 pounds, pushes the device 1 meter, and repeats the exercise 10 times.

- Teammate weight = 130 pounds  $\times$  4.45 newtons = 293 newtons
- Work in 1 repetition = Force  $\times$  distance = 293 newtons  $\times$  1 meter = 293 joules
- Total work done = Work in 1 repetition  $\times$  number of repetitions = 293 joules  $\times$  10 = 2930 joules

## Analysis

1. How does your work output compare with your teammates' output? Explain why there is a difference.
2. How could the total work done be useful to NASA?
3. If you were able to improve your device, what patterns did you see before and after the Improve stage?
4. Using the information that you calculated, defend your exercise device's ability to prevent muscle mass loss.

# Activity Five: Environment

## Educator Notes

### Learning Objectives

Students will be able to

- Compare and contrast the environments of Earth, the Moon, and Mars
- Design to scale an enclosed, self-sustainable habitat for astronauts on a deep space mission
- Create charts or diagrams of the life support systems or cycles within the habitat and explain how they function

### Challenge Overview

After watching a video on the fifth hazard for deep space astronauts, Hostile/Closed Environments, students will examine various celestial bodies to compare and contrast the environments. Students will work in teams to design ways to mitigate the dangers of a hostile environment. They are then challenged to create a conceptual habitat and identify ways to make it self-sustaining.

### Suggested Pacing

120 to 180 minutes

### National STEM Standards

Science and Engineering (NGSS)	
<p><i>Disciplinary Core Ideas</i></p> <ul style="list-style-type: none"> <li>• LS2.A: Interdependent Relationships in Ecosystems: Predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared.</li> <li>• LS2.B: Cycle of Matter and Energy Transfer in Ecosystems: Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem.</li> </ul> <p><i>Science and Engineering Practices</i></p> <ul style="list-style-type: none"> <li>• Developing and Using Models: Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.</li> <li>• Constructing Explanations and Designing Solutions: Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories.</li> </ul>	<p><i>Science and Engineering Practices (continued)</i></p> <ul style="list-style-type: none"> <li>• MS-ESS1-3: Analyze and interpret data to determine scale properties of objects in the solar system. [Clarification statement: Emphasis is on the analysis of data from Earth-based instruments, space-based telescopes, and spacecraft to determine similarities and differences among solar system objects. Examples of scale properties include the sizes of an object's layers (such as crust and atmosphere), surface features (such as volcanoes), and orbital radius. Examples of data include statistical information, drawings and photographs, and models.]</li> <li>• MS-LS2-2: Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems. [Clarification statement: Emphasis is on predicting consistent patterns of interactions in different ecosystems in terms of the relationships among and between organisms and abiotic components of ecosystems. Examples of types of interactions could include competitive, predatory, and mutually beneficial.]</li> <li>• MS-LS2-3: Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem. [Clarification statement: Emphasis is on describing the conservation of matter and flow of energy into and out of various ecosystems, and on defining the boundaries of the system.] [Assessment boundary: Assessment does not include the use of chemical reactions to describe the processes.]</li> </ul>
Mathematics (CCSS)	
<p><i>Mathematical Practices</i></p> <ul style="list-style-type: none"> <li>• CCSS.MATH.CONTENT.6.RP.A.1: Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities.</li> </ul>	

### Challenge Preparation

The educator should

- Read the introduction and background information and Educator Notes.
- Determine whether students will fill in the Comparison of Earth, Moon, and Mars handout or use the filled-in version; make copies as needed. (Both versions of the handout are located after the Student Handout.)
- Provide reading and video links to students to save time during the activity and prepare students for discussion.
  - “Growing Plants in Space.” [www.nasa.gov/content/growing-plants-in-space](http://www.nasa.gov/content/growing-plants-in-space)
  - “Can Space Gardening Help Astronauts Cope With Isolation?” [www.nasa.gov/feature/can-space-gardening-help-astronauts-cope-with-isolation](http://www.nasa.gov/feature/can-space-gardening-help-astronauts-cope-with-isolation)

## Hazards to Deep Space Astronauts

- Hazards of Human Spaceflight: Hazard 5: Hostile Closed Environments. (3:05) [www.youtube.com/watch?v=LgGt03MjHfA&feature=youtu.be](http://www.youtube.com/watch?v=LgGt03MjHfA&feature=youtu.be)
- Apollo 13: ‘Houston, We’ve Had a Problem.’ (7:00) [www.youtube.com/watch?v=MdvoA-sjs0A&pbjreload=101](http://www.youtube.com/watch?v=MdvoA-sjs0A&pbjreload=101)
- Real World: The Carbon Cycle – Essential for Life on Earth. (5:43) [nasaclips.arc.nasa.gov/video/realworld/real-world-the-carbon-cycle-essential-for-life-on-earth](http://nasaclips.arc.nasa.gov/video/realworld/real-world-the-carbon-cycle-essential-for-life-on-earth)
- Real World: Environmental Control on the International Space Station. (5:07) [nasaclips.arc.nasa.gov/video/realworld/real-world-environmental-control-on-the-international-space-station](http://nasaclips.arc.nasa.gov/video/realworld/real-world-environmental-control-on-the-international-space-station)
- Real World: Lunar Power Plant. (6:28) [nasaclips.arc.nasa.gov/video/realworld/real-world-lunar-power-plant](http://nasaclips.arc.nasa.gov/video/realworld/real-world-lunar-power-plant)
- Have videos preloaded for presentation.

### Materials

- Paper
- Graph paper
- Pencil
- Markers
- Scissors (optional)

### Safety

- Students should be aware of their surroundings and move carefully throughout the room when viewing another team’s work.
- Students should follow safe scissor protocol when using scissors.

### Introduce the Challenge

- Explain to students that life as we know it has adapted to the conditions on Earth. There are many natural systems working together to keep the conditions on Earth regulated so that we can continue to maintain life. The Moon, Mars, and other places in the solar system have different conditions that humans cannot adapt to without protection. Astronauts who travel beyond Earth are leaving their natural life-support system. Both their spacecraft and their eventual base must be designed to keep them alive, because their destination will have an environment that is not conducive to life as we know it.
- Have students watch and discuss the video “Hazards of Human Spaceflight: Hazard 5: Hostile/Closed Environments.” Explain that the best chance of long-term survival, whether in a spacecraft or on a celestial body, will be to keep the environment as similar to Earth as possible. Have students discuss the following questions:
  - What are important characteristics of long-term survival on Earth?
  - What modifications are necessary for survival on another celestial body like the Moon or Mars?
- Share the video “Apollo 13: ‘Houston, We’ve Had a Problem’” and have students discuss the following questions:
  - What essential element are the astronauts quickly running out of in this situation?
  - How could this situation be avoided in the future?
  - Why is it important to be for an environment to be self-sustaining?
  - Is it possible to be completely self-sustaining?



### Brain Booster

Aquaponics is a self-contained lunar plant growth chamber that can provide both protein and vegetation to astronauts. Fish living in the bottom provide nitrogen and phosphate for the plants, while the plants provide beneficial bacteria to convert ammonia and filter the water.

Learn more:

[spacescience.arc.nasa.gov/microecobiogeo/research/space-exploration-technologies/biology-is-the-technology-microbial-ecology-of-space-food-production/](http://spacescience.arc.nasa.gov/microecobiogeo/research/space-exploration-technologies/biology-is-the-technology-microbial-ecology-of-space-food-production/)



### On Location

Growing Beyond Earth is an educational outreach and citizen science program that reaches over 170 middle and high schools from Florida, Colorado, and Puerto Rico. NASA’s Kennedy Space Center plant production scientists Gioia Massa and Trent Smith train teachers who then receive plant growth chambers that mimic Veggie, the space garden residing on the International Space Station.

Learn more:

[blogs.nasa.gov/kennedy/2019/05/09/students-show-off-plant-research-at-symposium-in-miami/](http://blogs.nasa.gov/kennedy/2019/05/09/students-show-off-plant-research-at-symposium-in-miami/)

- Explain that in this activity students will be faced with a hostile environment. They will have to strategize ways to make the environment less hostile and utilize renewable resources to create a self-sustaining habitat in that new environment. Students will demonstrate their idea by designing a self-sustaining conceptual habitat and explain how elements necessary for life will be renewed, recycled, or created.
- Review the following criteria and constraints of the activity with students:

Criteria	Constraints
Draw cycles you are planning to integrate in your habitat and ecosystem.	Keep your habitat design to the scale size, no larger than 4.5 by 4.5 meters.
Habitat should be drawn to scale.	
You must have all necessary parts of living quarters, including airlock chamber, in your final presentation.	
Habitat may have more than one level.	

### Facilitate the Challenge

#### Ask

- Display a picture of a person, reptile, plant, fish, or other living thing and ask students what is necessary for this living organism to survive (e.g., food, water, and air).
- Discuss with students: We all have different habitats that we live in. We can and have learned to adapt to changes within our environment.
  - Display pictures of different ecosystems and discuss what is living there. Discuss biotic and abiotic factors.
  - It may be helpful to have students observe self-sustaining ecosystems and the organisms and cycles within them.
  - Ask students:
    - Could the living things in the ecosystem adapt in a different latitude? For example, from the equator at 0 degrees to Antarctica at 82 degrees south?
    - What happens to the oxygen after we use it? The water? Nutrients? (Have students explain the complete cycles.)
- Do a quick review of the cycles **if needed** (water, oxygen, nutrients, nitrogen, and carbon).
  - At their tables, assign each table a different “cycle” to draw and label with as many parts as they can without researching (e.g., water cycle, oxygen/carbon dioxide, nutrients, nitrogen, carbon, etc.). Note: Cycles curriculum should have already been covered with students prior to this activity.
  - Teams can partner up to share cycle information and see if other teams are able to add to the cycle the group originally created.
  - Have students use resources to research the cycles and add to their initial drawing. If time permits, have students present their cycles, or post them in the room so that all groups have access to the information.
  - References, if needed:
    - The Water Cycle. [gpm.nasa.gov/education/water-cycle](http://gpm.nasa.gov/education/water-cycle)
    - The Carbon Cycle. [svs.gsfc.nasa.gov/10494](http://svs.gsfc.nasa.gov/10494)
    - Why Is Carbon Important? [climatekids.nasa.gov/carbon/](http://climatekids.nasa.gov/carbon/)
    - What Is the Water Cycle? [climatekids.nasa.gov/water-cycle/](http://climatekids.nasa.gov/water-cycle/)

#### Imagine

- Ask students to imagine they were to go to a different celestial body. Is it possible to adapt and survive?
- Have students discuss with their table or neighbor whether they could survive on another planet or celestial body.
- Listen to some of their ideas (without commenting, so as not to restrict student creativity).

## Hazards to Deep Space Astronauts

### Plan

- Tell students that in order to decide whether (and how) we could adapt, we first need to examine the features of the celestial bodies. Introduce the Comparison of Earth, Moon, and Stars handout. Depending on available time and student ability:
  - Have students use science resources to fill out the chart (individually, as a team, or with the whole group); or
  - Provide students with the completed chart. Group them in small teams to review the differences between the three celestial bodies.
- Regroup and ask students if they think their original ideas from the **Imagine** phase would have kept them alive, now that they have done some research.
- Discuss the differences between Earth, Moon, Mars, and the other celestial bodies selected.
- Ask students the following questions:
  - What makes the environment hostile?
  - Could we grow food without intervention? Explain.
  - Are there some elements or features that can be useful? If so, what are they?
- Have students read the following articles:
  - “Growing Plants in Space.” [www.nasa.gov/content/growing-plants-in-space](http://www.nasa.gov/content/growing-plants-in-space)
  - “Can Space Gardening Help Astronauts Cope With Isolation?” [www.nasa.gov/feature/can-space-gardening-help-astronauts-cope-with-isolation](http://www.nasa.gov/feature/can-space-gardening-help-astronauts-cope-with-isolation)
- Share all or part of the video “NASA STEM Stars: Veggie.” [www.youtube.com/watch?v=7ukuCm7xrVY&t=44s](http://www.youtube.com/watch?v=7ukuCm7xrVY&t=44s)  
Note: The excerpt from time stamp 11:45 to 15:50 is most important for student viewing.
- Ask students to explain why they think it is important to be able to grow vegetation in space.
- Have students get in their small teams to discuss the elements needed in a habitat for it to be self-sustaining.
- Come together and discuss as a whole group. Be sure to discuss what is needed.

### Create

- Remind students that humans have adapted to life on Earth, but the environments on other celestial bodies are not conducive to life as we know it. To keep astronauts healthy, students need to create a habitat that is adaptable to the environment.
- Looking at the chart, have students choose a celestial body where they want to create a habitat that is self-sustainable.
- Remind students to check the criteria and constraints.
- Students will work in teams of no more than three and will be asked to do the following:
  1. Design and draw a habitat to scale that will sustain life on the celestial body of their choice.
  2. Explain and diagram the life support systems within the habitat.
  3. Create a diagram of how each of the following will be renewed, created, or recycled:
    - Oxygen
    - Water
    - Waste and garbage
    - Food
    - Power source
- Have students review their design with the whole group and talk things through to be sure that the habitat will be self-sustainable. Encourage them to review it with another educator or adult so that they can get another person’s point of view and then make improvements as needed.
  - Ecosystem resource if needed: [climatekids.nasa.gov/10-things-ecosystems/](http://climatekids.nasa.gov/10-things-ecosystems/)

### Test

- Have students meet with the instructor to discuss how the habitat will be self-sustaining. Be sure the teams can explain how all essentials for life are being met, how food is being produced, what the source of power is, and where their waste and garbage is going.
- Make suggestions or point out areas of improvement.

### Improve

- Have students return to their teams and adjust their habitat to address suggestions for improvement or missed objectives.
- Have students update their drawings and explanations as needed

### Share

- Have each team present their design to the whole group and explain how they will establish the habitat to be self-sustainable.
- Optional: Share students' results on social media using #NextGenSTEM. Be sure to include the module and activity name.

### Extensions

- Have students test their ideas for the habitat on an enclosed ecosystem and try to sustain the life of a Plant-stronaut. Have them create a table-top-size, sealed ecosystem to test their ideas. Put a plant in the ecosystem and test the sustainability of their habitat.
- Have students add additional levels to the ecosystem for their Plant-stronaut.
- Have the whole group collaborate by taking the best parts of each habitat to design a Super Habitat.

### References

Life Support Systems

[www.nasa.gov/stem-ed-resources/life-support.html](http://www.nasa.gov/stem-ed-resources/life-support.html)

Living and Working in Space: Habitat

[www.nasa.gov/pdf/176994main\\_plugin-176994main\\_HSE\\_TG2-1.pdf](http://www.nasa.gov/pdf/176994main_plugin-176994main_HSE_TG2-1.pdf)



## Activity Five: Environment

### Student Handout

#### Your Challenge

You will compare environments of different celestial bodies and decide which celestial body has the best conditions to support a self-sustaining habitat for astronauts. You will design or draw to scale a conceptual enclosed, self-sustainable habitat for astronauts on a deep space mission. You will draw diagrams that shows how you renew and recycle the needed items to sustain life.

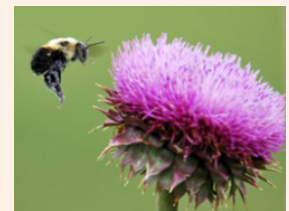
Criteria	Constraints
Draw cycles you are planning to integrate in your habitat and ecosystem.	Keep your habitat design to the size no larger than 4.5 by 4.5 meters.
Habitat should be drawn to scale.	
You must have all necessary parts of living quarters, including airlock chamber, in your final presentation.	
Habitat may have more than one level.	

#### ? Ask

- Look at the pictures displayed. What is necessary for each of the following to survive:
  - Person?
  - Reptile?
  - Plant?
  - Fish?
  - Amphibian?
- Look at the pictures of the different ecosystems provided and discuss with your neighbor what you see. Talk about the biotic and abiotic factors.
- As you examine each picture, discuss the following questions:
  - What is needed for all the living things pictured to adapt to live in a different latitude?
  - How could the organism adapt to live in Antarctica if they were from a tropical environment?
  - What happens to the oxygen after the animals use it?
  - What happens to the water after it is consumed?
  - What happens to the nutrients that were taken in?
- As a team, draw the cycle your instructor has assigned and label as many parts as possible without researching.
- Partner and share cycle information with another team and see if you can add to each other's work.
- Research your cycle, using a credible science resource. See if there is any information missing and fill it in.
- Share your information as your instructor directs.

#### Fun Fact

Ultraviolet (UV) light has shorter wavelengths than visible light. Although UV waves are invisible to the human eye, some insects, such as bumblebees, can see them. This is similar to how a dog can hear a whistle just outside the hearing range of humans.



Learn more:

[science.nasa.gov/ems/10\\_ultravioletwaves](https://science.nasa.gov/ems/10_ultravioletwaves)

#### Career Corner

Dr. Gioia Massa works on space crop production for the International Space Station and future missions at the NASA Kennedy Space Center. She led the science team for the in-space validation of the Veggie experiment hardware and now leads an interdisciplinary group studying how both fertilizer and light affect the flavor of crops grown in Veggie.

Learn more:

[www.nasa.gov/content/veggie-plant-growth-system-activated-on-international-space-station](https://www.nasa.gov/content/veggie-plant-growth-system-activated-on-international-space-station)

### Imagine

- Imagine you were to go to a different celestial body. Is it possible to adapt and survive?
- Discuss with your table or neighbor whether you think you could survive on another planet or celestial body and how.

### Plan

- In order to decide if you could adapt and how, you first need to examine features from other potential worlds. You will be provided with a chart of characteristics of the Earth, Moon, and Mars.
- After filling in or looking at the data with your team, answer the following questions:
  - What makes the environments hostile?
  - Could we grow food without intervention? Explain.
  - Are there some elements or features that could be useful? If so, what are they?
- Read the following articles:
  - Growing Plants in Space. [www.nasa.gov/content/growing-plants-in-space](http://www.nasa.gov/content/growing-plants-in-space)
  - Can Space Gardening Help Astronauts Cope With Isolation? [www.nasa.gov/feature/can-space-gardening-help-astronauts-cope-with-isolation](http://www.nasa.gov/feature/can-space-gardening-help-astronauts-cope-with-isolation)
- Watch the excerpt of “NASA STEM Stars: Veggie” (11:45 to 15:50). [www.youtube.com/watch?v=7ukuCm7xrVY&t=44s](http://www.youtube.com/watch?v=7ukuCm7xrVY&t=44s)
- Why do you think it is important to have the programs that were talked about in the article and in the video?
- How can these programs benefit the space program and future missions?
- In your team, discuss and write your ideas regarding what environmental elements and other items are needed in a habitat for it to be self-sustaining.

### Create

- Humans have adapted to live on Earth. The environments on other celestial bodies are not conducive to life as we know it. To keep astronauts healthy, you must create a habitat that is adaptable and self-sustainable.
- Choose a celestial body from the chart that you think will be the best for adaptation. You will be using this body to create a habitat that is self-sustainable.
- Check the constraints and criteria.
- Work in teams to do the following:
  1. Design and draw a habitat to scale that will sustain life on the celestial body of your choice.
  2. Explain and diagram the life support systems within the habitat.
  3. Create a diagram of how each of the following will be renewed, created, or recycled:
    - Oxygen
    - Water
    - Waste and garbage
    - Food
    - Power source
- Review your design with the team and talk things through to be sure that the habitat will be self-sustainable. Practice explaining your design to another adult or teacher and have them give you feedback.
- Review the feedback that you were given and make improvements as needed.

### Test

- Meet with the instructor to discuss the how the habitat will be self-sustaining. Be sure you can explain how all essentials for life are being met (e.g., how food is being produced, the source of power, where the waste and garbage is going, etc.).

## Hazards to Deep Space Astronauts

### Improve

- Return to your team and adjust your habitat to address suggestions for improvement or missed objectives.
- Update your drawings and explanations as needed.

### Share

- Present your design to everyone and explain how you will establish the habitat to be self-sustainable.

## Comparison of Earth, Moon, and Mars (Fillable Chart)

**Directions:** Using science resources, fill in the chart to compare features of Earth, the Moon, Mars, and (optional) one other celestial body of your choice. Optional links to use for the chart:

- Mars Exploration Program: [mars.nasa.gov/all-about-mars/facts/](https://mars.nasa.gov/all-about-mars/facts/)
- Planetary Data: [nssdc.gsfc.nasa.gov/](https://nssdc.gsfc.nasa.gov/)
- Temperature Variations and Habitability: [icp.giss.nasa.gov/education/modules/eccm/eccm\\_student\\_1.pdf#page=3](https://icp.giss.nasa.gov/education/modules/eccm/eccm_student_1.pdf#page=3)

	Earth	Moon	Mars	Other _____
Atmosphere composition				
Distance from Earth at closest point, km	N/A			
Distance from Earth at farthest point, km				
Air pressure, mb (millibars)				
Terrain composition				
Terrain texture				
Length of day				
Surface gravity, m/s <sup>2</sup>				
Temperature range, °C				
Radiation or protection from radiation				
Water (evidence or states of water)				
Signs of life				
Volcanic activity				
Other storms or hazards				
Special features or areas to place your habitat in or near	----			

## Comparison of Earth, Moon, and Mars (Completed Chart)








Resource links to use with the chart:

- Mars Exploration Program: [mars.nasa.gov/all-about-mars/facts/](https://mars.nasa.gov/all-about-mars/facts/)
- Planetary Data: [nssdc.gsfc.nasa.gov/](https://nssdc.gsfc.nasa.gov/)
- Temperature Variations and Habitability: [icp.giss.nasa.gov/education/modules/eccm/eccm\\_student\\_1.pdf#page=3](https://icp.giss.nasa.gov/education/modules/eccm/eccm_student_1.pdf#page=3)

	Earth	Moon	Mars
<b>Atmosphere composition</b>	78 percent nitrogen 21 percent oxygen	Basically none. Some carbon gases (CO <sub>2</sub> , CO, and methane), but very little of them. Pressure is about one-trillionth of Earth's atmospheric pressure.	95 percent CO <sub>2</sub> 2 percent nitrogen 2 percent argon 1 percent oxygen
<b>Distance from Earth at closest point, km</b>	N/A	357,000	54.6 million
<b>Distance from Earth at farthest point, km</b>	N/A	407,000	401 million
<b>Air pressure at surface, mb (millibars)</b>	1,014	>1	4 to 9, depending on the season
<b>Terrain composition</b>	Oxygen, silicon, aluminum and iron are the elements that make up the crust. The terrain includes weathered crust material, organic material, and moisture.	Silicon and oxygen bound in minerals, glass produced by meteorite impacts, and small amounts of gases (e.g., hydrogen) implanted by the solar wind	Silicon and oxygen, iron, magnesium, aluminum, calcium, and potassium
<b>Length of day, hour</b>	24	27.3 Earth days	24.7
<b>Surface gravity, m/s<sup>2</sup></b>	9.8	1.62	3.71
<b>Temperature range, °C</b>	10 to 20	-233 to 123	-60 to -125
<b>Radiation or protection from radiation</b>	Atmosphere and magnetic field block out most radiation.	Cosmic rays, solar flares, the lunar surface itself is radioactive	Solar and GCR radiation, no protection
<b>Water (evidence or states of water)</b>	Water in all states	Water ice	Traces of water, evidence of a watery past
<b>Signs of life</b>	Life!	no	
<b>Volcanic activity</b>	Yes	Yes	Yes, largest volcano in solar system, Olympus Mons, is 3 times larger than Mount Everest
<b>Other storms or hazards</b>	Earthquakes, floods, etc.	Meteorite strikes, water ice at South Pole	Dust storms, tornadoes
<b>Special features or areas to place your habitat in or near</b>	N/A	Answers may vary	Lava tubes beneath the ground Answers may vary






## Appendix A.—Rubrics

### A.1 Engineering Design Process (EDP)

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



## A.2 Problem-Based Learning Process

PBL Step	Novice (0)	Apprentice (1)	Journey person (2)	Expert (3)	Level of student knowledge (Score)
 <b>Meet the problem</b>	Student does not identify the problem	Student incorrectly identifies the problem	Student identifies part of the problem	Student fully and correctly identifies the problem	
 <b>Explore knowns and unknowns</b>	Student does not identify knowns and unknowns	Student incompletely identifies knowns and unknowns	Student identifies knowns and unknowns using experience but uses no resources	Student completely identifies knowns and unknowns using experience and resources	
 <b>Generate possible solutions</b>	Student does not brainstorm	Student generates one possible solution	Student provides two solutions	Student provides three or more possible solutions	
 <b>Consider consequences</b>	Student does not identify any consequences	Student determines inaccurate or irrelevant consequences	Student identifies consequences accurately	Student identifies consequences accurately and provides a rationale	
 <b>Present findings</b>	Student does not communicate results	Student shares random results	Student shares organized results, but results are incomplete	Student shares detailed, organized results with the larger group	
<b>Total</b>					

## Appendix B.—Glossary of Key Terms

**Abiotic factors.** The nonliving components that influence an ecosystem

**Analog.** Situation on Earth that produces physical, mental, and/or emotional effects on the body similar to those experienced in space; analog studies help prepare for long-duration missions

**Atrophy.** Thinning or loss of muscle tissue

**Biotic factors.** The living components that influence an ecosystem

**Cartilage.** Strong tissue that cushions between bones

**Celestial body.** A natural object outside the Earth's atmosphere, such as the Moon, Sun, planet, or star

**Confinement.** The state of being enclosed (such as being confined within borders or walls)

**CONNECT.** The acronym NASA uses for the mitigation focus points for preventing side effects from isolation and confinement—community, openness, networking, needs, expeditionary mindset, countermeasures, and training and preparation

**Coronal mass ejection (CME).** A violent release of gas and magnetic fields from the solar corona

**Countermeasure.** An action or device designed to prevent a danger

**Femur.** Longest bone in the human body, extending from the hip to the knee

**Galactic cosmic radiation (GCR).** A dominant source of radiation that must be dealt with aboard current spacecraft and future space missions within our solar system; galactic cosmic rays originate outside the solar system and are likely formed by explosive events such as supernova

**Human Research Program (HRP).** A NASA program in which HRP scientists and engineers work together to discover the best methods and technologies to support safe, productive human space travel

**Humerus.** Long bone in the upper arm that runs from the shoulder to the elbow

**Isolation.** The state of being set apart from others

**Joint.** The location where two bones meet

**Ligament.** Strong tissue that connects bone to bone

**Magnetosphere.** Area of space around a planet that is controlled by the planet's magnetic field; provides safety from most forms of radiation coming from space

**Mitigation.** The process or result of making something less severe, dangerous, painful, harsh, or damaging

**Osteoporosis.** Bone disease that occurs when the body loses too much bone, makes too little bone, or both

**Pandemic.** Disease outbreak occurring over a wide geographic area (such as multiple countries or continents) and typically affecting a significant proportion of the population

**Pelvis.** Basin-shaped body structure that connects the trunk and the legs

**Side effects.** A secondary and usually adverse effect (as of a drug)

**Sievert.** The standard unit for radiation in the International System of Units (SI)

**Solar energetic particles (SEPs).** Energetically charged particles (such as electrons and protons) traveling much faster than ambient particles in the space plasma, at a fraction of the speed of light

**Vertebrae.** Small bones that form the backbone and protect the spinal cord





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