A UNIT OF STUDY FOR GRADES 3–8

BEYOND SPACESHIP EARTH

CHILDREN'S MUSEUM INDIANAPOLIS

A Unit of Study for Grades 3–8

Acknowledgements

BEYOND SPACESHIP EARTH

The Beyond Spaceship Earth exhibit is made possible by lead gifts from Lilly Endowment Inc., Eli Lilly and Company Foundation, The Heritage Group, Patricia Schaefer, and a NASA grant, with major support provided by R. B. Annis Educational Foundation, Church Brothers Collision Repair, The Dorsey Foundation, and Susan and Steve Haines.

National Aeronautics and Space Administration

The material contained in this unit of study is based upon work supported by NASA under award Number NNX14AD06a. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Aeronautics and Space Administration.

CHILDREN'S MUSEUM INDIANAPOLIS

The Children's Museum of Indianapolis is a nonprofit institution dedicated to creating extraordinary learning experiences across the arts, sciences, and humanities that have the power to transform the lives of children and families. It is the largest children's museum in the world and serves more than 1 million people across Indiana as well as visitors from other states and nations.

VISIT THE MUSEUM

The museum provides special programs and experiences for students as well as teaching materials and professional development opportunities for teachers. To plan a visit or learn more about educational programs and resources, visit the Teacher section of the museum's website at childrensmuseum.org

COVER PHOTO COURTESY OF NASA

Astronaut Nicholas Patrick, STS-130 mission specialist, participates in the mission's third and final session of extravehicular activity (EVA) as construction and maintenance continue on the International Space Station.

NASA Photos: Unless otherwise indicated, all photos used in this unit of study are courtesy of the National Aeronautics and Space Administration.

BEYOND SPACESHIP EARTH

TABLE OF CONTENTS

Enduring Idea

Living and working in space is a true STEM experience. It requires understanding the physical forces related to microgravity and using technology to study our planet. Space scientists and astronauts must apply knowledge from a wide range of science disciplines to engineer transport vehicles and to design and use communication, navigation, and life-support systems for spacecraft. The ability to use data strategically to solve problems is also essential. In this unit of study, students will apply science, technology, engineering, and math concepts and skills as they learn about the challenges of living and working in space.

Above: NASA astronaut, Tracy Caldwell Dyson, Expedition 24 flight engineer, views Earth from the Cupola module of the ISS. PHOTO CREDIT: NASA

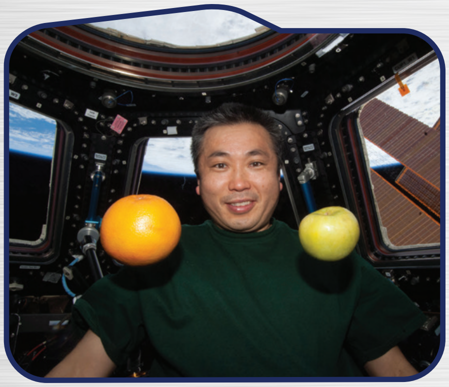
The Exhibit

Beyond Spaceship Earth at The Children's Museum of Indianapolis recreates the interior of several modules from the International Space Station where visitors discover how astronauts make themselves at home as they orbit the Earth. Through interactive games, families and children monitor scientific experiments and perform some of the jobs that astronauts carry out both inside and outside the ISS. They learn about the challenges of daily life in a microgravity environment as space station crew members eat, sleep, work, and exercise to keep up their physical strength. The Schaefer Planetarium and Space Object Theater immerses visitors in the early spaceflights that led to the development and construction of the ISS. Some may be surprised to learn about the strong Indiana connections to NASA programs.

PHOTO CREDIT: CAN STOCK PHOTO

The Unit of Study

Buckle up! You are in for a great ride! This unit of study explores the International Space Station through STEM experiences in space science education. But space science education isn't limited to just stars and planets. It's about becoming part of a team that asks Earth-based questions to find answers about life. And it's about inspiring students to explore mysteries beyond Earth's surface. It's also about visionaries, thinkers, dreamers, and inventors. In this unit of study, students become a spacecraft crew and launch from Earth to discover how microgravity affects the orbit of the International Space Station. Crew members become investigators and learn about properties of water in microgravity. They work together to explore light as energy and consider how this influences the use of certain materials both in space and on Earth. Students compare living and working in space and on Earth. They investigate the food astronauts eat in space and how it compares to food on Earth. Students study closed systems by building a terrarium and explain how these systems apply to enhancing life in orbit. They learn the importance of exercise and how to prepare for long-term expeditions in outer space. Crew members find that space exploration is complicated and fascinating work! Astronauts carry out experiments to examine the human body, test materials, and analyze elements. They also have to maintain and sometimes repair the ISS and use tools in their work that must be adapted to function in a microgravity environment. As the final mission in this unit of study, crew members use unit experiences to design and create a three-dimensional module or tool for the International Space Station.



What's Ahead?

Introductory Experiences

What would it be like to be an astronaut and live on the International Space Station? Making the transition from Earth to space isn't easy. There are many physical and mental challenges to face but the possibilities for expanding our knowledge are great. These introductory experiences begin to immerse students in the scientific study of everyday life in a place that is out of this world!

Introductory Experience 1: Prepare for Liftoff!

Students take on their new roles as members of the International Space Station crew. They create crew logbooks to record notes, questions, experiments, and findings. They decide what personal items they could take and consider what basic needs must be met to enable astronauts to live and work in space.

Introductory Experience 2: What Is the International Space Station?

Students form research teams as they examine questions about the role of the International Space Station and how it was built. They research questions about the ISS, create posters as graphic organizers, and share information through a gallery walk. As they prepare to take off for the ISS, they create their own mission patches that reflect what they expect to learn.

Lesson 1: Orbiting Earth

Student crew members explore microgravity and the unique challenges astronauts must overcome to carry out their duties in Earth orbit. They examine the way the International Space Station was constructed and conduct experiments to explore the behavior of water in microgravity, examine how different materials and colors respond to light and darkness, and determine how solar energy is transferred to power the ISS.

Lesson 2: Living in Outer Space

Students investigate the similarities and differences between daily life on board the ISS in a microgravity environment to living on Earth. They carry out experiments on food items to determine how well they would work in space. They also consider how the human body performs in microgravity and how astronauts train before and during spaceflights in order to remain healthy.

Lesson 3: Working in Outer Space

Students examine the tools and equipment astronauts use while working in space and consider how microgravity requires tools that are designed specifically for this environment. Students take on an engineering design challenge as they create a new instrument to be used in space.

What Will Students Learn?

As a result of the *Beyond Spaceship Earth* unit of study, students are inspired to use STEM skills as they simulate living and working in space. In the culminating experience, they apply this knowledge to an engineering challenge. Unit experiences address selected standards in engineering, physical science, and life science as presented in the 2016 Indiana Academic Standards and the Next Generation Science Standards.

What Will Students Be Able to Do?

Students will

- work together in research teams and keep careful records of research experiences and results
- develop an understanding of gravity and microgravity
- compare physical properties of liquids on Earth and in microgravity
- demonstrate that light is a form of energy and learn how energy is generated on the ISS
- explain how the ISS is constructed to protect astronauts from the extreme temperatures of space
- infer that the color of materials will affect temperature and comfort while living and working on the ISS
- examine the way foods are selected and prepared for long-term spaceflight
- investigate preservation of food by dehydration and explain why this is a good way of preserving and storing food for consumption in space
- build and examine the needs of a closed life-support system and explain how the ISS is engineered to meet the daily needs of astronauts

- examine how exercise helps reduce the effects of microgravity on the human body and conduct tests to determine how different types of exercise help astronauts train for their missions

- explain why astronauts need special equipment and tools to work in space
- discuss the benefits of science research in space

- design and carry out a science research experiment and report on results
- work in teams to brainstorm, design, and build a new tool or a 3D module for the ISS

Getting Started

Classroom Environment

The *Beyond Spaceship Earth* unit invites all earthlings to become involved in space exploration. Establish the classroom environment for this experience by posting colorful pictures from the NASA Education Resource Center or other online resources. Create bulletin boards with themes like "Out of This World," "Space Cadets," or "Shoot for the Stars." Make sure students have web access for their research, and encourage them to visit nasa.gov. The NASA website has a wealth of information with pages designed specifically for both teachers and students.

There also are many community members who might want to provide their expertise or talk with students about their work or avocations. For example, astronomy clubs could share information about the tools they use to observe objects and events in space. Help students explore space-science related careers.

The ISS is a laboratory that carries out experiments for scientists on Earth. Engage students in hosting an aerospace/STEM career day and invite scientists to discuss the many different types of experiments that are being carried out in space. Also ask people in science-related careers, such as a test pilot, a meteorologist, an electrical engineer, a geologist, or a robotics engineer, to meet with students in person or online for the culminating engineering challenge presentation. Visit the NASA website for a long list of possible aerospace careers: nasa.gov/audience/forstudents/careers/profiles/index.html.

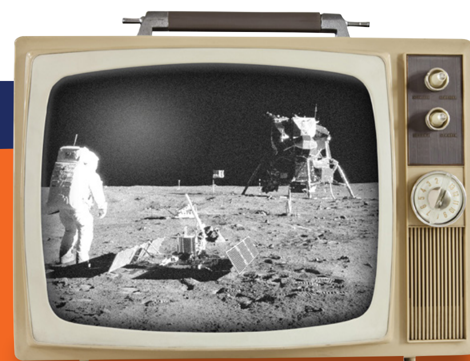
Invite other school staff to join in the excitement. Your art teacher could introduce students to space-related artworks and engage students in creating artworks of their own. Invite your food services staff to talk about nutrition and food preparation on Earth and how that is different from preparing food for astronauts in space. Ask the physical education teacher to assist in planning the **Building Strength for Space** exercise stations in **Lesson 2**. The PE teacher may want to design a unit on muscle building to connect to the astronaut physical training experience.

Crew Logbooks

Crew members of the International Space Station are expected to keep individual logbooks in which they record their experiences and keep notes on experiments and work programs on a daily basis. Astronauts and other scientists must keep accurate accounts of their experiences to help them remember details, analyze data, and compare their results with the work of others. They are also documenting historic events and preparing the way for future investigations. Ask students to play the role of ISS crew members, including the practice of keeping a logbook, and discuss why this is important to the mission of spaceflight and exploration. Students will enjoy the opportunity to personalize the logbooks with their own artwork as they use them to keep notes, make drawings related to scientific experiments and equipment, and record and reflect on their own learning.

Above: NASA astronaut, Dr. David Wolfe, records data from a cell growth experiment in his crew log book. PHOTO CREDIT: NASA

Family Connections



Engage family members to share their childhood memories of space-science accomplishments. Show students John F. Kennedy's speech that encouraged America to go to the moon. Ask grandparents what they remember about the speech. Do they remember Neil Armstrong and Buzz Aldrin walking on the moon? Parents may be able to share their childhood stories about watching dramatic shuttle launches that led to building the International Space Station.

Above: On July 20, 1969, America's Apollo 11 Lunar Module pilot Buzz Aldrin and mission commander Neil Armstrong were the first humans to set foot on the moon. PHOTO CREDIT: NASA

Vocabulary

International Space Station
crew logbooks
mission patches
modules

You will need

- crew logbooks – one plain notebook per student
- one small suitcase
- one small duffel or other bag
- photos of the ISS under construction
- nasa.gov for details and videos about the ISS
- construction paper
- marker pens
- scissors
- digital scales
- Student Handout, page 12

Introductory Experiences

Students begin to take on the roles of future crew members of the International Space Station and generate questions about daily life as astronauts. They consider what is needed to sustain life and work in space as they begin to research and report on the ways that the space station has been designed to meet these needs.

Above: NASA astronaut Karen Nyberg, Expedition 37 flight engineer; Russian cosmonaut Fyodor Yurchikhin (center), commander; and European Space Agency astronaut Luca Parmitano, flight engineer, pose for a photo in the Kibo laboratory of the ISS. (Oct. 14, 2013) PHOTO CREDIT: NASA

Focus Questions

- What is the ISS? When and how was it built?
- What personal items would you want to take to the space station?
- Why are there limitations on the size and weight of items crew members can take?
- What is absolutely necessary for people to live in space?
- Are personal items also important? Why or why not?
- What aspects of daily life in space are you curious about?
- What are some of the main components of the space station and how do they make life possible?

Right: The Zvezda Service Module became part of the International Space Station in July 2000. PHOTO CREDIT: NASA

Introductory Experience 1: Prepare for Liftoff!

In this experience, students consider what it would be like to prepare for a six-month mission to the International Space Station, where crew members can take only a few small personal items.

Above: Astronaut Cady Coleman, ISS-27 flight engineer, brought her flutes aboard the ISS in her small allotment of personal items. (March 17, 2011) PHOTO CREDIT: NASA

Procedures

- Introduce the unit by displaying a small suitcase and ask students to think about personal items they like to take with them when they travel. Ask them to discuss some of the items they usually take. Ask students if anyone likes to take photos or keep a diary to help them remember a trip.

- Open the suitcase to reveal a set of **crew logbooks**, one for each student. The logbooks can be divided into sections for introductory experiences and each of the ***Beyond Spaceship Earth*** lessons in this unit.

- Let students know that logbooks are standard equipment for all astronauts on the **International Space Station**. They begin to use the logbooks long before they leave Earth as soon as they begin training for their mission. Astronauts are expected to keep careful notes related to the technical work they will be doing in space. Discuss why this would be an important responsibility. Some astronauts also like to use the logbooks to record their day-to-day experiences while in space. Ask students to speculate about why this also would be important.

- Explain to students that the Crew Logbook will be used throughout the entire unit of study for recording their questions and taking lesson notes. Distribute the logbooks and allow time for crew members to personalize them.

- Next, ask students to take about 5 minutes to make a list of personal items they would want to pack if they were preparing to leave on a six-month expedition as the next crew of the International Space Station. Remind them that they don't have to include food, clothing, or toiletries like toothbrushes and toothpaste. Those will be provided for them on the ISS.

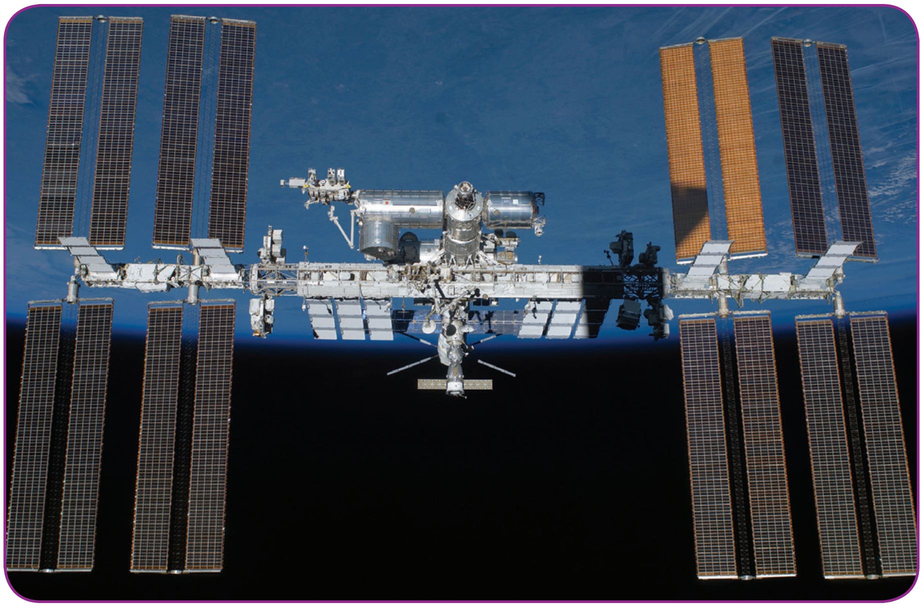
- Next, explain that there will not be room on the spacecraft to take even a small suitcase. They can only take 20 personal items in a small bag. Allow crew members to revise their travel list to 20 items. Then, reveal that items have to be small and lightweight. Set a total weight limit for the personal items, such as 1.36 kg (3 lbs.).

PHOTO CREDIT: CAN STOCK PHOTO

PHOTO CREDIT: CAN STOCK PHOTO

- Give students time to practice packing items and using scales to weigh them in order to understand the weight limitations of the bag. If students have items at home they wish to include, have them estimate their weight. Have students review their lists to determine what they will have to leave behind on Earth in order to meet the limitations. Have students use their logbooks to make a final list of the personal items they are able to include in their bags.

- Ask students: In addition to the personal items, what else will you need to live and work on the International Space Station? Ask students to think about this question and use their logbooks to write down questions that they have about the ISS. Are there other questions they are curious about? Have them use the logbooks to record their questions for further research.



Introductory Experience 2: What Is the International Space Station?

Students generate questions about the International Space Station. They research its purpose, major components, how it was constructed, and the roles astronauts play while on board. They share findings through a gallery walk and develop mission patches for their own expedition.

Above: NASA and its international partners completed assembly of the International Space Station in the fall of 2011. PHOTO CREDIT: NASA

Procedures

- Show students photos or a video of the exterior of the International Space Station.
- Remind students that they are members of a crew about to blast off to the ISS, where they will live for six months.
- Ask: What do you want to know about your new home on the ISS? Have students share questions from their logbooks and help them generate more questions if necessary.
- In addition to personal interest questions, help students generate "nuts and bolts" questions that relate to the construction and operation of the ISS and its different **modules** and components, such as:
  - When was the ISS built? What countries were involved and what role did each country play in the construction process?
  - How did astronauts assemble the ISS? How long did it take?
  - What are the modules that make up the ISS and what are their functions?
  - Where does the ISS get its power? How is the power stored and used?
  - What countries do ISS astronaut crews come from? How do they get to and from the space station?
  - How does ISS get the supplies it needs to keep operating? What supplies are needed and how often do they need to be replaced?
  - How is the ISS designed to deal with emergencies? What kind of safety equipment does it have?
- Based on interests, have students form small teams to research a question and create a poster illustrating the information they have found.
- After teams have completed their posters, have them post their work around the classroom or a school hallway and plan a "gallery walk." Give all students time to view the posters and take notes using the graphic organizer on page 12.
- Hold a "debriefing" session and ask the crew to discuss the interesting things they discovered about their new home in space. Give them time to record in their logbooks the facts that they found most surprising and the things they want to know more about.

Left: Expedition 48-49 prime crew members Takuya Onishi of the Japan Aerospace Exploration Agency (left), Anatoly Ivanishin of Roscosmos (center), and Kate Rubins of NASA (right) field questions from reporters during their final Soyuz qualification exams. (May 27, 2016) PHOTO CREDIT: NASA/STEPHANIE STOLL

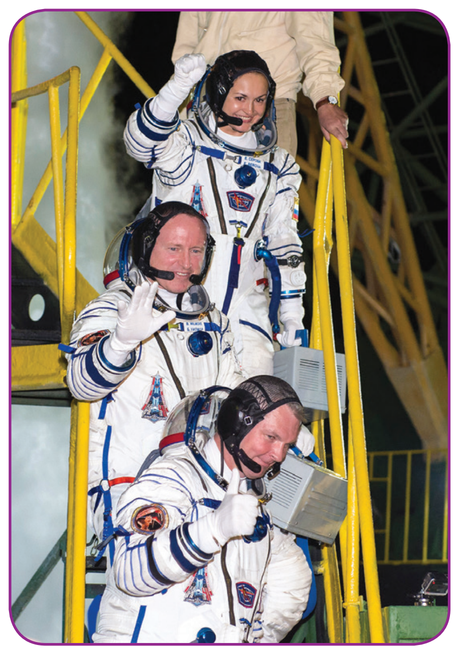
Left: This patch for the historic one-year expedition to the ISS includes the names of the 2014 full-year crew, Commander Scott Kelly and Flight Engineer Mikhail Kornienko. The stars represent the 13 who joined the crew periodically and worked together as a team.

Culminating Experience: Mission Patches

- Congratulate the crew on their research and let them know it's about time to begin their training for the ISS. Before they do, they should consider the purpose of their mission.
- Ask them if they have been able to identify the major purpose of the International Space Station and why several nations have worked together to build it and staff it with astronauts. What do scientists expect to learn from the ISS?
- Discuss the role of the ISS as a laboratory designed to test different materials and develop ideas that will help human beings live and work both in space and on Earth.
- Ask students: What do you want to learn on your expedition? What is the purpose of your mission?
- Share information from nasa.gov to show students examples of **mission patches** and discuss the meaning of different symbols used.
- Explain that International Space Station crews work together to design patches that are unique for their mission.
- Tell the crew that they have the opportunity to work in teams to design their own expedition patches. Form teams of three or four students to create patches that reflect what they expect to learn as they continue to study the ISS.
- Have teams sketch preliminary designs in their logbooks and list the elements they want to include in their mission patch.
- Provide construction paper, marker pens in a variety of colors, and scissors for each team member to create his or her own patches.
- Ask teams to explain the symbols and meaning of their patches. Students may want to paste their patches on the cover or the inside pages of their logbooks.

Above: The insignia for Expedition 44 shows the ISS poised to study Earth, the sun and cosmos that lie beyond.

Above: NASA astronaut Mark Kelly wears the STS-121 mission patch. PHOTO CREDIT: NASA



Above: Expedition 41 Soyuz crew members wearing mission patches wave farewell prior to boarding the Soyuz TMA-14M spacecraft for launch to the ISS. (Sept. 25, 2014)
PHOTO CREDIT: NASA/AUBREY GEMIGNANI

STUDENT HANDOUT

Gallery Walk – What's New

Make as many copies as necessary to review all of the posters.

Student Name: ____

Poster Topic

What did you learn that was new and interesting?

____

____

What would you like to learn more about?

____

____

Poster Topic

What did you learn that was new and interesting?

____

____

What would you like to learn more about?

____

____

Poster Topic

What did you learn that was new and interesting?

____

____

What would you like to learn more about?

____

____

Poster Topic

What did you learn that was new and interesting?

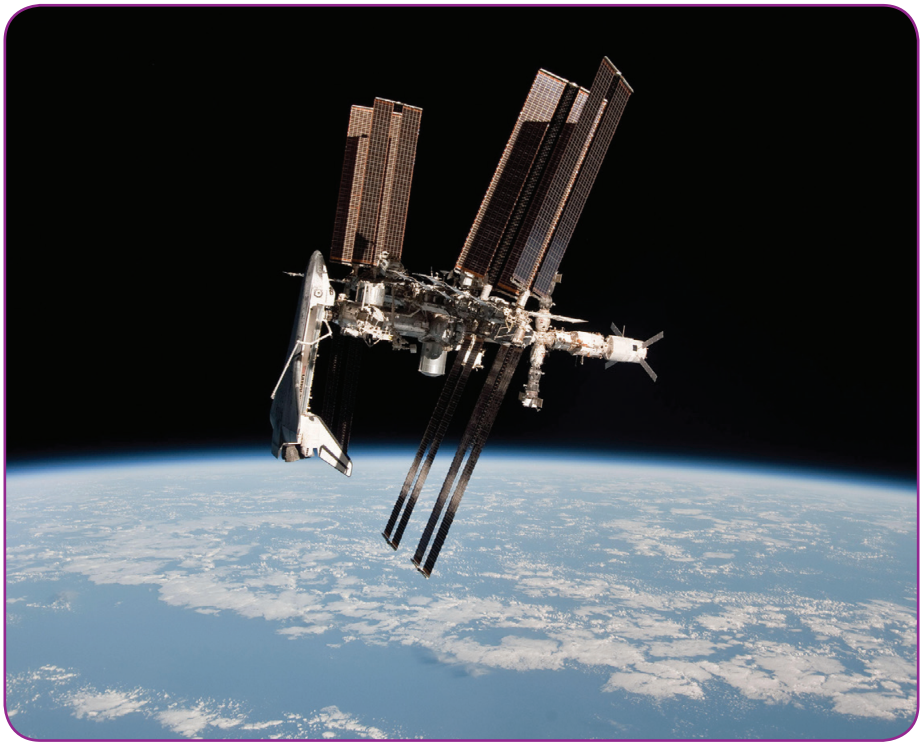
____

____

What would you like to learn more about?

____

____



Lesson 1 : Orbiting Earth

In this lesson, the student crew members examine the way the ISS orbits Earth in a state of free fall and begin to explore the way the ISS was constructed in a microgravity environment. They experiment with liquids to discover how they behave in space and determine how the materials used in the construction of the ISS respond to extreme temperatures.

Above: The space shuttle docked to the ISS. (June 16, 2011) PHOTO CREDIT: NASA

Objectives

Students will

- identify the major challenges that humans face when leaving Earth for space
- identify the objects in the solar system that orbit the sun and explore the way gravity keeps the Earth in orbit around the sun and the moon in orbit around the Earth
- use tracking websites, maps, and globes to locate the ISS as it orbits the Earth
- explore the physical forces related to gravity and microgravity
- consider how microgravity affects materials, objects, processes, and living things
- compare the properties of water to other liquids on Earth
- experiment with the behavior of water on Earth and compare that to its behavior in microgravity
- predict how other liquids might behave in microgravity
- determine why the ISS experiences major changes in temperature as it orbits the Earth
- examine the way different colors and materials respond to changes in temperature and consider the implications for the ISS
- explain how solar power is captured and used as an energy source for the ISS

Focus Questions

- What causes one body in space to orbit another?
- What are gravity and microgravity?
- How do launch engineers get materials to build and maintain the ISS in Earth orbit?
- How does the International Space Station stay in orbit?
- What are some of the problems associated with working in a microgravity environment?
- What are physical properties of liquids in space and on Earth?
- Why does the ISS encounter extreme changes in temperature as it orbits the Earth?
- How is the ISS constructed to protect astronauts from these extremes?
- How does the ISS generate and use electricity?

Above: NASA's first large-scale solar power generation facility was unveiled in November 2009 at Kennedy Space Center. Representatives from NASA, Florida Power and Light Company, and SunPower Corporation commissioned the 1-megawatt facility as the first element of a major renewable energy project at Kennedy. PHOTO CREDIT: NASA

You will need

Experience 1: Free Fall

1 or 2 class periods

- ❑ small plastic ball and one heavier ball
- ❑ small slingshot or a simple catapult device
- ❑ NASA web video – *A Day in the Life Aboard the ISS*
- ❑ models or images of the sun/Earth/moon system and the solar planetary system
- ❑ crew logbooks

Experience 2: Water in Space

2 class periods

Materials for 4 water stations including:

- ❑ student instructions for each station, page 20
- ❑ containers of different sizes and shapes
- ❑ measuring cup or graduated cylinder
- ❑ 2 digital scales
- ❑ eye droppers or pipettes
- ❑ paper towels, waxed paper, aluminum foil
- ❑ toothpicks
- ❑ water
- ❑ ice cubes in cooler
- ❑ ice tongs
- ❑ container
- ❑ heat lamp
- ❑ Student Lab Sheets – Water Works – pages 21 and 22
- ❑ crew logbooks

Experience 3: Play It Cool

1 or 2 class periods

- ❑ 3 thermometers for each team of 4 or 5 students
- ❑ 1 sheet black construction paper per team
- ❑ 1 sheet white construction paper per team
- ❑ Sunlight, preferably outdoors
- ❑ crew logbooks

Experience 4: Current Events

- ❑ Solar-powered toys, calculator, or flashlight for demonstration
- ❑ Solar energy kit that includes a solar mini-panel, power cord with plugs, motor, and capacitor

(see the **Resources** section for solar kit sources)

Vocabulary

angle
gravity
conductor
current
electrical circuit
electromagnetic waves
energy
electricity
force
free fall
friction
inertia
liquid
mass
microgravity
orbit
radiant energy
solar
surface tension
thrust
volume
weight

Academic Standards

Indiana Science Standards (2016)

K–12 Science and Engineering Process Standards

SEPS.1, SEPS.2, SEPS.3, SEPS.4

Physical Science

4.PS.1, 4.PS.2, 4.PS.4, 4.PS.5; 5.PS.1, 5.PS.3, 5.PS.4; 6.PS.2, 6.PS.4. 6.ESS.1; 7.PS.4, 7.PS.5. 7.PS.6

National Standards

Next Generation Science Standards

Physical Science

4-PS3-2, 4-PS3-4; 5-PS1-2, 5-PS1-3, 5-PS2-1; MS-PS1-2, MS-PS1-4, MS-PS1-5, MS-PS3-3

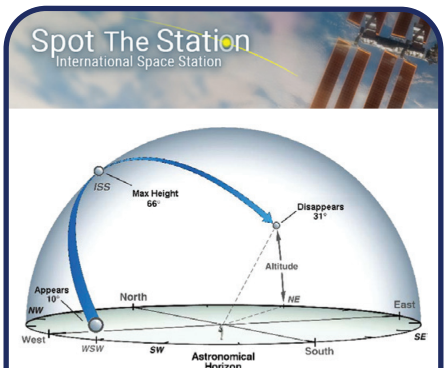
Experience 1: Free Fall

In this experience, students work as a crew to develop a scientific understanding of the challenges of living on the International Space Station in a microgravity environment. They examine models of the sun/Earth/moon system and the planetary system to learn about how one body orbits another. They develop a working definition of microgravity by studying a series of demonstrations focused on how an object gets into Earth orbit and remains in free fall.

Above: European Space Agency astronaut Luca Parmitano, Expedition 36 flight engineer, works with Microgravity Science Laboratory (MSL) hardware in the Destiny laboratory of the International Space Station.. (Aug. 20, 2013) PHOTO CREDIT: NASA

Procedures

- Congratulate students on their preparation work. They have designed mission patches and their personal items are packed and ready for launch, but it's not that easy to get to the International Space Station. It is necessary to reach **orbit** so the crew can board the ISS.
- Show students an animated video of the ISS being constructed in space: youtube.com/watch?v=yRqUPjl3tTQ
- Ask students to consider how each of these components arrive in space. Explain that all construction materials and the astronauts who build and maintain the ISS have to be launched by rocket to a precise location where they orbit the Earth.

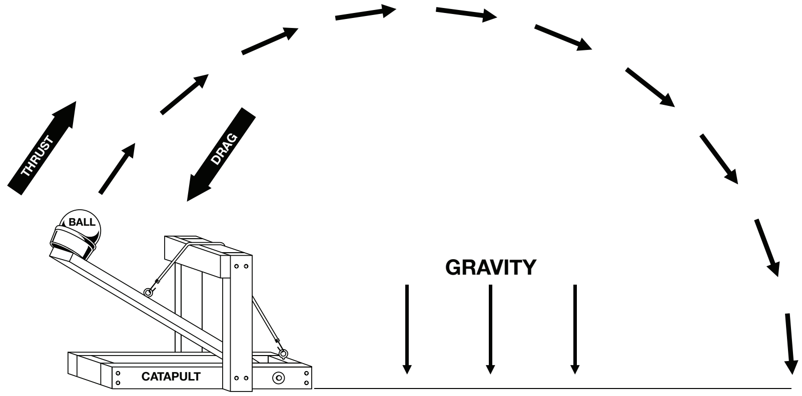


Track the ISS

Visit the NASA website to learn how you can track the International Space Station as it completely orbits the Earth every 90 minutes.

spotthestation.nasa.gov/sightings/

- Ask students if they can give any examples of objects that are in **orbit**—a regular, repeating path that one object in space takes around another.
- Show students models or images of the sun/Earth/moon system. Discuss the way the Earth both spins on its axis and orbits the sun.
- Have students work in groups of 3 as they act out the movements of the Earth as it spins on its axis and orbits the sun, and the moon as it orbits the Earth. Don't get dizzy! (To extend learning, have students demonstrate the movements of each of the planets as they orbit the sun.)
- Ask students: What keeps the Earth and the moon in their orbits? Explain that **gravity**, the attraction of one object to another, helps keep the moon in orbit around the Earth and the planets and other bodies in orbit around the Sun.
- Help students develop a definition of gravity as a force that pulls objects together. It is the force that pulls the moon toward the Earth and the Earth toward the sun. Earth's gravity also is the force that pulls an object down toward the planet's surface.
- To demonstrate, hold a ball in the air and ask students to predict what will happen if it is dropped. Drop the ball and ask students to explain why it fell to the floor. Some students may offer gravity as an explanation.
- Ask students: Suppose we wanted to put the ball into orbit around the Earth? How would that be possible?
- Demonstrate how an object can be launched into the air by using a ball and a catapult to provide **thrust**. Carry out this demonstration in an open area such as the school gym or outdoors where students can study it safely.



Newton's Laws of Motion

The First Law of Motion

An object at rest (an object that is not moving) will stay at rest unless an unbalanced **force** acts on it. In other words, an object will not move unless a force pushes or pulls it. The second part of the law states that an object in motion will stay in motion at a constant speed and in a constant direction unless an unbalanced force acts on it. The tendency to remain in place or to continue moving in the same direction is called **inertia. Friction** is an unbalanced force that acts on an object, causing it to slow down and eventually stop.

The Second Law of Motion

The **acceleration** of an object is equal to the force on the object divided by the mass of the object. Greater force is needed to give an object with greater mass the same acceleration as an object with lower mass. For an object with a constant mass, the acceleration of the object increases as the force on the object increases. However, if the force on an object with constant mass is also constant, the acceleration of the object decreases if the object encounters an unbalanced force, such as friction.

The Third Law of Motion

When an object exerts a force on a second object, the second object exerts a force on the first object that is equal in size but opposite in direction. For example, when a steel ball bearing is dropped on a hard surface, the ball exerts a downward force on the floor. At the same time, the floor exerts an upward force on the ball. This upward force causes the ball to bounce up.

IMAGE CREDIT: WIKIMEDIA COMMONS

- Ask students to observe the path that the ball takes during several launches and sketch diagrams illustrating the process in their logbooks.
- Try adjusting the **angle** for higher and lower launches. Students will notice that the ball always falls back to Earth in an arc.
- Ask students to explain what has happened. Help them understand that the **thrust** from the catapult worked against gravity while other forces, such as **drag**, the friction caused by the push of air against the moving ball, slowed it down and gravity pulled the ball down to Earth again.
- Ask students what would happen if a heavier ball were used. Help students demonstrate that if the ball has greater **weight,** greater force would be needed to launch it at the same speed and distance as the lighter ball.

Teacher note: For students below Grade 6, the distinction between weight and mass may be a difficult concept. Students in Grades 6–8 should be able to understand that mass is weight and volume. They may want to practice engineering skills by designing and building a catapult to experiment with various objects and observe how mass relates to motion.

- Have students add labels to their diagrams showing the forces, including gravity, thrust, and drag, that are acting on the ball.
- Introduce Newton's Laws of Motion and help students understand how they explain not only the behavior of the ball on Earth, but also the behavior of bodies in space.
- Have students consider this question: What would it take to put the ball into orbit? After discussion, explain that if we could launch the ball high enough, at the appropriate angle, and maintain the right speed, inertia would keep it moving while the influence of gravity would cause it to constantly fall in an arc around the curved surface of the Earth. Then the ball would be in **free fall**, orbiting the Earth. What happens when an object is in free fall?
- Have students use their logbooks to write down predictions about how different everyday objects, tools, and materials, like liquids, will behave in free fall, along with any questions they may have for future exploration.
- Show students a segment of the NASA video *A Day in the Life Aboard the ISS* featuring a *Station Tour* by Expedition 33 Commander Sunita Williams. Preview the segment to determine how much you want to use at this time. See the Sleeping in Space section of the STEM on station site.
- Ask students to watch closely and describe how being in a **microgravity** environment is different from being on Earth, where gravity is much stronger. What does the prefix "micro" in the word microgravity mean?
- Explain that some people describe their experience of a microgravity environment as being "weightless." This isn't really true. Objects that appear to float in microgravity are really falling at the same rate as the objects around them. Gravity is still at work but is much weaker in Earth orbit than it is on Earth's surface.

Are the Forces with You?

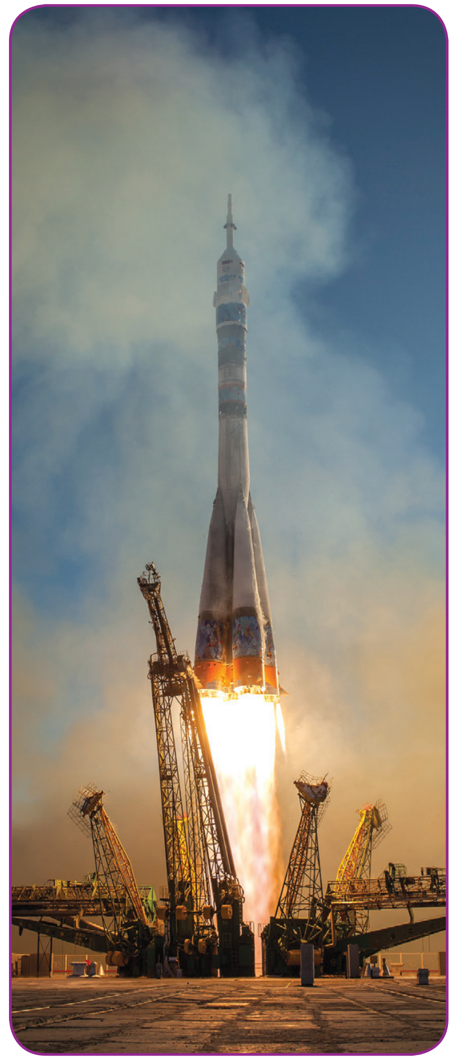
Gravity is the attraction between objects. All objects with mass (volume and weight) are affected by gravity. Engineers must determine how to counteract Earth's gravity to get a spacecraft into orbit. This is accomplished by using a force (a push or pull on an object) called thrust, which propels an object in a specific direction.

Thrust from engines is the force used to get a rocket off the ground. The push produced by the rocket engines works against the force of Earth's gravity, which pulls objects down. When a spacecraft is launched from Earth, scientists have to use enough force to get the rocket into space and at the correct angle to achieve orbit. Once in orbit, the spacecraft is in a state of free fall, creating a condition called microgravity. A free-falling object is falling under the sole influence of gravity. As long as the spacecraft maintains its orbit, it remains in continuous free fall following the curvature of the Earth.

Above: NASA astronaut Scott Kelly takes a final portrait of Expedition 43 crew members (clockwise from top) Terry Virts, Samantha Cristoforetti and Anton Shkaplerov before they enter their Soyuz spacecraft and close the hatches. PHOTO CREDIT: NASA TV

Timing Is Everything

How will the crew reach the International Space Station to begin their mission? It takes about six hours from launch to boarding the ISS. The timing must be perfect. Sometimes the rendezvous takes longer. Space engineers must consider Earth's rotation and the position of the International Space Station in order to dock a spacecraft successfully. To launch a vehicle into Earth orbit, scientists find the best time of year based on where Earth's orbit will be around the sun. This is called a "launch window." Engineers must choose the right time to launch a rocket with its payload and use thrust from the rocket engine to escape Earth's surface and achieve orbit. This is challenging for engineers because the rocket must work against the force of gravity. Earth is spinning on its axis at about 1,000 mph. If the rocket is aimed in the same direction Earth is already rotating, it will get a good boost. When it reaches a specific point, the rocket releases the spacecraft headed for the International Space Station. The rocket, now out of fuel, drops back to Earth. The vehicle docks and joins the ISS in free fall as it orbits the planet. An occasional boost from its engines keeps the International Space Station, and its crew and cargo, in the proper position to remain in orbit.



Above: The Soyuz TMA-11M rocket launched with Expedition 38 Soyuz Commander Mikhail Tyurin of Roscosmos, Flight Engineer Rick Mastracchio of NASA, and Flight Engineer Koichi Wakata of the Japan Aerospace Exploration Agency onboard, at the Baikonur Cosmodrome in Kazakhstan. (Nov. 7, 2013). PHOTO CREDIT: NASA/

Experience 2: Water in Space

Students continue to explore differences between gravity and microgravity by comparing the behavior of water on Earth with video evidence of water in microgravity. They explore and learn about qualities of water through experimentation.

Above: NASA astronaut Rick Mastracchio, Expedition 38 flight engineer, works at the Fluid Science Laboratory (FSL) in the Columbus laboratory of the International Space Station. (Jan. 9, 2014) PHOTO CREDIT: NASA

Procedures

- To review student learning from **Experience 1**, ask students to share some of their observations and questions about microgravity from their logbooks.
- Focus on their questions about how materials, particularly water, might behave differently on the ISS.
- Explain that these are particularly important questions and remind them that one of the purposes of the space station is to examine questions like these. In fact the ISS has a module that is a laboratory specially designed for experimenting with liquids in microgravity.
- Ask students to explain the properties of a **liquid**. Let students know that part of their crew's mission is to examine the behavior of liquids on Earth to serve as the basis for understanding how and why they might behave differently in a microgravity environment. Why this might be important?
- After discussing the possible applications of this research, explain to students that the first liquid they will study is water.
- Place students in teams of 3 or 4 to rotate among water stations set up to examine different properties and record observations on the Student Handout on pages 21–22.

Station 1 – Volume: Students pour water into containers of different shapes and sizes and observe that water pours freely and conforms to the shape of the container.

Station 2 – Weight: Students weigh a specific amount of water in different containers and predict the weight of the water. After subtracting the weight of each container they will confirm that the weight is the same.

Station 3 – State: Students weigh an ice cube in a small container. They record the weight and then place the container under a heat lamp. Students predict if the weight will be the same after the ice cube melts. After the ice cube returns to a liquid state, they weigh it again, compare with previous data, and explain the outcome. (Plan for wait time to give ice cubes time to melt. Focus on accurate measurements.)

Station 4 – Surface Tension: Students use pipettes or eye droppers to test how a few drops of water behave on different surfaces, such as paper towels, waxed paper, and aluminum foil.

Laboratory in Orbit

A major function of the International Space Station is to serve as a laboratory to examine the way liquids and other materials behave differently in space than they do on Earth. One of the ISS labs is called the Fluid Science Laboratory (FSL). It was designed by the European Space Agency and launched in 2007. The FSL is used to conduct fluid physics experiments in the microgravity of space. Scientists want to study liquids because it might help us better understand fluid characteristics for engines, power plants, and heating/cooling systems. It might also help us improve life support systems aboard the ISS.

- Check to see if all the groups had the same outcomes. If not, ask students to consider why there might have been differences, including the possibility of human error.
- Discuss students' observations regarding the properties of water. They have seen that water takes on the form of whatever container it is in, takes up space (**volume**), and has **weight**. Explain that anything that takes up space and has weight has **mass**.
- Discuss the fact that water becomes a solid under cold temperatures and converts to a liquid at warmer temperatures. Ask: Did the volume and weight change as it converted from one state to another? Students should discover that the water has conserved its mass.

Teacher Note: Students in middle school should be able to explain how changes in temperature affect the movement of the particles (atoms/molecules) that make up water, resulting in changes from liquid to solid and solid to liquid.

- At **Station 4**, students observe that drops of water soak into materials like paper towels but form beads on waxed paper and aluminum foil. Encourage students to speculate about why this is the case.
- Ask students: Have you ever seen a small bug sitting on the surface of a body of water?
- What did you notice about the bug? What did you notice about the water? It looks like it bends from the weight of the bug.

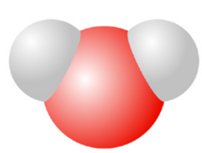

PHOTO CREDIT: CAN STOCK PHOTO

Above: Because water molecules are attracted to each other, drops of water cling together on top of a penny.

- Explain that the surface of the water acts as "skin." It holds together because water **molecules** are attracted to each other. This is called **surface tension**.
- Congratulate students on their observations of some important characteristics of water on Earth. Ask them to predict how water might behave in microgravity and record their predictions in their logbooks.

H_2O is so attractive!

Water molecules are made up of 2 atoms of hydrogen and 1 atom of oxygen (H_2O) connected by a strong covalent bond caused by the attraction of negatively and positively charged electrons. The oxygen molecule has two pairs of electrons that are not part of the covalent bond. Both have a strong negative charge. They are very attracted to the positive charge of the electrons of the hydrogen atoms in other water molecules. Because water molecules have both a positive and a negative "end" they attract each other and form a highly organized molecular network. This why H_2O molecules cling together and produce surface tension.



- After viewing the video, ask students if water on the ISS behaved the way they predicted. Focus on students' observations that water, unless it is confined to a container, forms blobs in microgravity that seem to float because they are in free fall.
- Explain that even in microgravity, water molecules are still attracted to each other and stick together, so are still affected by surface tension.
- Encourage the entire crew to discuss their experience, compare it to what was viewed in the video, and record any new discoveries in their logbooks.

Extending experiences:

- Try experimenting with other liquids such as isopropyl alcohol and cooking oil. Ask: Which liquids seem to have molecules that are attracted to each other?
- Place a drop of water on waxed paper. Dip a toothpick into dish detergent. Gently touch the water with the toothpick. How does detergent affect the water's surface tension? Detergent is made from molecules that have a charged end and a longer uncharged end. The detergent molecules stretched out over the surface of the water with the charged end in the water and the uncharged end sticking out. The water molecules at the surface are attracted to the charged end of the detergent molecules. The detergent acts against the surface tension. This reduces the surface tension so the water does not hold a round shape and then breaks apart and spills over.

WATER WORKS
WATER STATION INSTRUCTIONS

Cut these student instructions apart and post at each water station.

Station 1 – Volume

Instructions:

1. Take turns carefully pouring water into containers of different shapes and sizes.
2. Observe the water as you pour it.
3. Record observations on your Lab Sheet.

Station 2 – Weight

Instructions:

1. Weigh a measuring cup. Record the weight on your Lab Sheet.
2. Pour in water to measure 1 Cup and weigh the cup and water.
3. How much does the water weigh? Use your Lab Sheet to subtract the weight of the cup from weight of the cup and the water.
4. Select a different container and record the weight.
5. Pour the water from the measuring cup into the new container and weigh.
6. Predict the weight of the water. Use your Lab Sheet to subtract the weight of the container from the weight of the container and water.
7. Record the weight and compare with the answer in number 3.

Station 3 – State

Instructions:

Use the tongs to remove one ice cube from the cooler and place in the container.

1. Weigh the ice cube and container and record the weight.
2. Place the container and ice cube under a heat lamp until the ice cube melts. The lamp is hot. Do not touch!
3. Weigh the container and the melted ice cube.
4. Compare the weight of the melted ice cube with the frozen ice cube.

Station 1 – Surface Tension

Instructions:

1. Use pipettes or eyedroppers to place 2 or 3 drops of water on a piece of paper towel, waxed paper, and aluminum foil. Use your Lab Sheet to describe what you see.
2. Use a toothpick to try to drag the drops of water around on the waxed paper and aluminum foil. Try to break them apart and pull them back together again. Use your Lab Sheet to describe what you see.

STUDENT HANDOUT

WATER WORKS – STUDENT LAB SHEET

Name: ____

Station 1 – Volume

Watch the water as you pour it from one container to another. Describe what you see.

Observations: ____

____

____

____

____

____

____

____

Station 2 – Weight	Grams
1. How much does the cup weigh?	
2. How much do the cup and water weigh?	
3. How much does the water weigh?	
Subtract: _________ (water and cup) – _________ (cup) = water	
4. How much does the new container weigh?	
5. How much do the container and water weigh?	
6. Predict how much the water weighs.	
7. Subtract the weight of the container from the weight of the container and water.	

Was your prediction correct? ____

Does the water weigh the same as before, more, or less? ______________________________

Station 3 – State	Grams
1. What is the weight of the frozen ice cube and container?	
2. How much do the melted ice cube and container weigh?	

Has the weight of the ice cube changed? ______________________________

Is it more, less, or the same? ______________________________

Explain the outcome: ______________________________

____

____

____

Station 4 – Surface Tension

How does water behave on different surfaces?

Observations:

Paper towel: ______________________________

____

Waxed paper: ______________________________

____

Aluminum foil: ______________________________

____

How does it behave when you try to move it around?

Observations: ______________________________

____

____

SUMMARY: After experimenting with water at the four different stations, what can you say about the way water behaves on Earth?

Observations: ______________________________

____

____

Experience 3: Play It Cool

Nothing about the design of the ISS is by accident, not even the color of the material used to construct the space station. In this experience, students will explore how different colored materials are affected by light energy. This investigation will require students to observe, record differences, reach conclusions, and discuss their results. This should lead them to infer that the color of the materials used to construct the ISS will affect temperature and comfort while living and working on board.

Above: Sunlight and shadows play on the surfaces of the International Space Station. PHOTO CREDIT: NASA

Procedures

- Begin this experience by asking: Have you ever noticed your summer clothes are often lighter colors than your winter clothes? Do you have any ideas why this might be? Discuss student suggestions and focus on the idea that lighter colors might feel cooler and more comfortable.
- Remind students that the ISS orbits Earth every 90 minutes, moving through intense rays from the sun to the deep shade of the Earth. Ask: How might conditions on the ISS change between being in sunlight to being in the dark of the Earth's shadow?
- Help students understand that these two conditions result in very different temperatures in space: extreme heat in the sunlight and very frigid temperatures in the shade.
- Note that Earth experiences temperature changes too. For example, in the summer, when the Northern Hemisphere is angled toward the sun, temperatures go up. In the winter, when it is angled away from the sun, temperatures go down.
- Have students suggest reasons we don't experience the extreme temperature differences on Earth that are felt in space. Explain that without the protection of Earth's atmosphere, temperatures would be too intense for human beings to survive.
- Ask students: When you are at home on Earth, what do you do to adjust the temperature? Students will probably think of air conditioning, a furnace or fireplace, a fan, and adding or subtracting sweaters, socks, and shoes. Ask: Do you think the same techniques would be enough to change the temperature in space?

Going to Extremes

Objects in space heat up by absorbing sunlight and cool off by giving off infrared energy. The ISS is designed and built with thermal balance controls to keep the crew comfortable. If the ISS did not have temperature controls, the inner temperature would rise to 250°F on the sun-facing side and plummet to -250°F on the Earth side. To help control temperature inside, the ISS is insulated with a reflective blanket, called Multi-Layer Insulation, or MLI, made of Mylar and other polymers.

Understanding the properties of different materials is very important for living and working in a space environment. Engineers must design for the excessive solar temperature changes that a spacecraft or astronaut will encounter. At the same time, the sun is a colossal source of energy that can be used for power. Scientists continually research ways to control the energy and use it over time. All of this knowledge is transferred to use on Earth and in space.

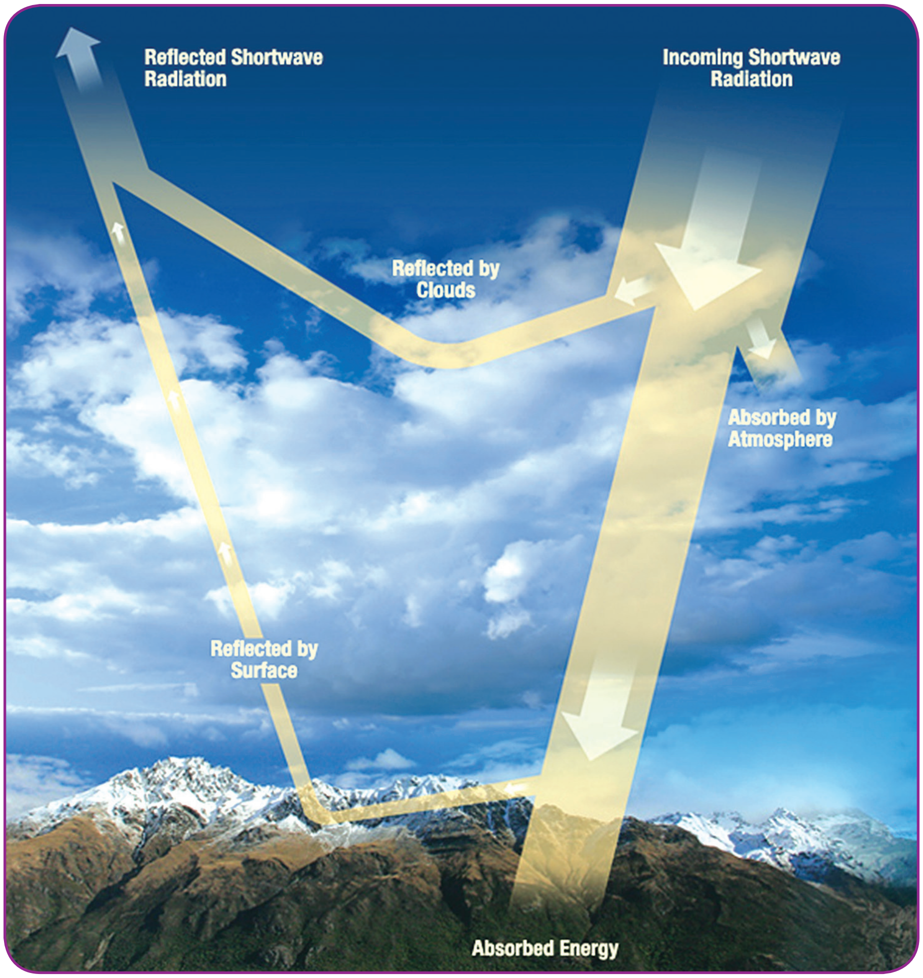


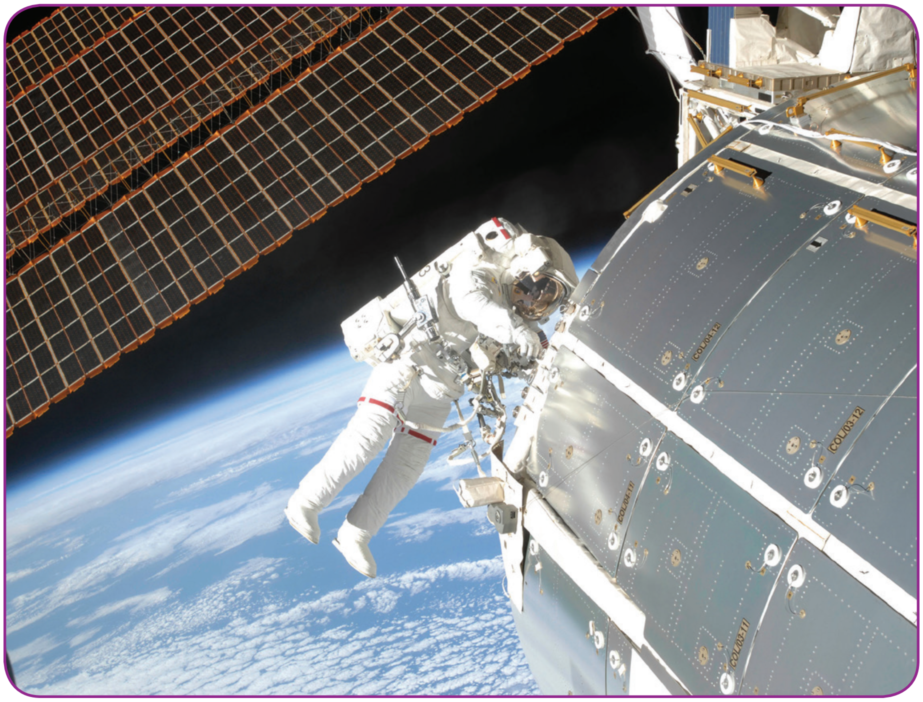
IMAGE CREDIT: NASA

- Now that they understand the effect of sunlight on temperature, ask students again to consider why summer clothing is often made in light colors.
- Explain that the sun produces **energy** in the form of electromagnetic waves. An **electromagnetic wave** is a wave of energy that results from an electric charge. We see part of the wave as light but we feel part of the wave as heat. Explain that different colors absorb different amounts of this energy from the sun, resulting in different temperatures.
- Have students predict which colors will absorb the most energy.
- Explain that students are going to conduct an experiment to see how the dark and light colored materials react to electromagnetic waves, or light energy.

Color Counts

Dark colors absorb more sunlight than light colors. That's why dark colors get warm faster than light colors. Light colors reflect more **radiant energy**, so they stay cooler in the sunlight. Radiant energy is the energy of electromagnetic waves. It is a form of energy that can travel through space.

- Divide students into groups of 4 or 5 and distribute to each group copies of the Student Lab Sheet **How Hot Is It?** on page 26, 3 thermometers, a sheet of white construction paper, and a sheet of black construction paper.
- Have students fold a piece of each sheet of paper into an envelope to hold a thermometer.
- Students should record the current temperature shown on each thermometer and record their initial readings on the student handout.
- Next, have students place a thermometer in each of the two paper envelopes.
- Have students place their two envelope-enclosed thermometers and the third thermometer side-by-side underneath their light source. It is best to conduct this experiment outdoors in direct sunlight, if possible, or use lamps with 100-watt incandescent bulbs.
- Ask each group to predict which of their thermometers will record the highest temperature.
- After 10 minutes, students should record the temperatures on the thermometers again. Be sure to read the temperature as soon as the thermometers are removed from the envelopes, before the air temperature can change the reading. Record readings on the student handout.
- Allow the thermometers to return to room temperature or to the temperature in the shade. Emphasize with students that this is very important to get an accurate reading of how much the light is heating up the thermometers.
- Replace the thermometers in the envelopes, return them to the light and wait another 10 minutes to repeat the readings. Record the new readings on the student handout.
- Repeat this process one more time, recording the temperature readings again after another 10 minutes.
- Students should calculate temperature differences at each reading by subtracting the lowest temperature from the highest temperature and recording the results on the handout.



Above: Astronaut Randy Bresnik, STS-129 mission specialist, participates in the mission's second session of extravehicular activity (EVA) as construction and maintenance continue on the International Space Station. PHOTO CREDIT: NASA

Extending Experience

Have more advanced students repeat the temperature readings three times at 10-minute intervals, graph the results, and calculate the average temperature change for each thermometer.

- Ask students: Which envelope's thermometer registered the greatest change in temperature? Which registered the least? Did one color of envelope consistently have higher temperatures than the other?
- Ask students to discuss their observations and speculate about the reasons for the results they found.
- If students need more direction, ask: What caused this difference in temperature? Why did the set of thermometers covered in black paper register higher temperatures than the ones covered in white paper?
- Help students understand that the difference is due to the color of the paper they used for their envelopes. Different colors absorb different amounts of energy from the light. Black absorbs the most light of any color, so the temperature will be higher. White reflects light and absorbs very little so the temperature will be lower.
- Ask: Do these results match your team's predictions?
- Note that the temperature differences seen in this experiment are small—only a few degrees. Ask students to imagine what would happen if the different colored envelopes were exposed to a stronger source of electromagnetic waves.
- Have students consider what would happen to an object like the ISS, which is in Low Earth Orbit where it receives less of the insulating effect of Earth's atmosphere.
- Based on this experience, ask students to suggest what colors make the most sense for materials used to construct the ISS. Remind students that the color only matters when the ISS is exposed to electromagnetic waves while in sunlight, not when it is in the shade.
- Show students images of the ISS and of astronauts during space walks. Ask: What colors are the modules of the ISS and the astronauts' space suits? Is this consistent with the conclusions you reached during your experiment with the thermometers?

Teacher tip

Background information and ideas for this experience can be found in *Energy and Heat* by Kathryn Whyman. If you have a sunny classroom with windows, it would be best to use sunlight for this investigation since the sun is the source of radiant energy that both affects and powers the ISS. If you are using lamps, the bulbs will probably become very hot. Caution students not to touch the lamps!

STUDENT LAB SHEET

HOW HOT IS IT?

Team #: ____

Student Name: ______________________________________

BLACK		
First Trial	°F	°C
Current temperature		
After 10 minutes		
Second Trial	°F	°C
Current temperature		
After 10 minutes		
Third Trial	°F	°C
Current temperature		
After 10 minutes		

WHITE		
First Trial	°F	°C
Current temperature		
After 10 minutes		
Second Trial	°F	°C
Current temperature		
After 10 minutes		
Third Trial	°F	°C
Current temperature		
After 10 minutes		

CONTROL		
First Trial	°F	°C
Current temperature		
After 10 minutes		
Second Trial	°F	°C
Current temperature		
After 10 minutes		
Third Trial	°F	°C
Current temperature		
After 10 minutes		

Observations: ____

____

____

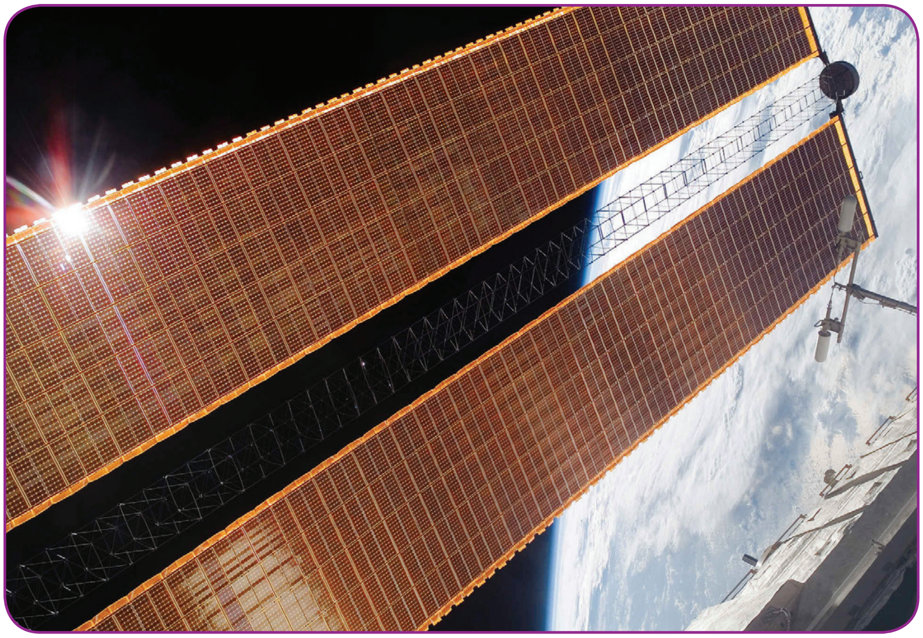
____

____

____

____

____



Experience 4: 'Current' Events

Students learn that the International Space Station gets its electrical power from the sun. They examine the way a solar panel creates and transfers an electrical current to power a small machine. This information helps students understand how the space station generates the energy it needs to operate.

Above: The long panels on the International Space Station are solar arrays. They are designed to capture enough energy to power its operations and life support systems. PHOTO CREDIT: NASA

Procedures

- Ask students to think about where the energy comes from to power computers, fans, air conditioning, lights, and other functions on the ISS. After their preliminary research about the ISS and their investigations in **Experience 3**, they may realize that the space station's power source is the sun.

- To demonstrate, have students examine a solar-powered toy, calculator, or flashlight to identify how the device captures energy from the sun. Explain that each of these devices has a small solar panel that collects sunlight and changes it into electricity. Ask students to discuss what happens if power fails at home or school. How does it affect our lives?

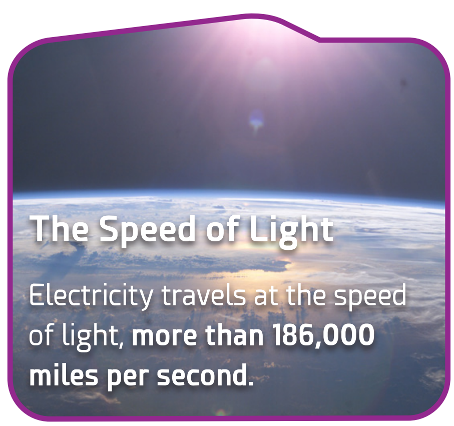
- Ask students where the electricity we use at home and school comes from. What are some sources that generate electricity? Examples may include solar, wind, coal, hydroelectric, battery, biomass, nuclear, natural gas, petroleum, and geothermal sources.

- Ask students: What is **electricity**? What do they use at home or at school that is powered by electricity? How does electricity work? What is needed to create electricity?

- Explain to students that electricity is a form of **energy** and that electrical energy can be transferred in different ways. They will be experimenting to see how the electrical energy produced by the sun can be transferred and put to use.

Power from the Sun

The International Space Station is constructed to protect astronauts and equipment from the extreme heat and cold of space. It is also built to capture radiant energy from the sun and convert it into the electricity that powers its operations. The ISS has large solar panels that move and adjust to maximize solar power. Sunlight is gathered by arrays of solar cells in the panels. Photons from the sun strike a semiconductor surface that excites electrons and routes them through conductors that create an electrical current. During daylight, the arrays gather power and distribute it for use in the ISS. Some of that power is saved into batteries to be used when the ISS moves into darkness. The ISS has over 8 miles of wire in its electrical system.



The Speed of Light

Electricity travels at the speed of light, **more than 186,000 miles per second.**

Above: The Zarya Control Module provides battery power and fuel storage for Soyuz and Progress space vehicles. PHOTO CREDIT: NASA

- Place students in teams and provide each team with a solar electricity kit including a mini-solar panel, a power cord with plugs on each end, and a small motor. (See the **Resources** section for sources of solar-powered electricity kits that enable students to build their own solar-powered machines.)
- Explain to teams that it is their mission to discover how to transfer the electricity from the solar panel to power a small motor by creating a **circuit**.
- Explain that a circuit uses a source for electricity, the solar panel in this case, connected by a complete circle of wires carrying electricity. The wire is called a **conductor**. The flowing electricity is called the **current**.
- Allow 10 minutes for teams to connect the solar panel, wires, and motor and determine if electricity is being transferred.

Teacher Tip

Make sure the solar panel is in direct sunlight and students are matching the polarity of the plugs to the jacks on the solar panel and the motor. If necessary, use a lamp with a 60-watt incandescent bulb, instead of sunlight, to power the solar panel. Have students measure the distance and place the solar panel no closer than 15 cm (about 6") from the light bulb. If the light is too close, the amount of heat from the bulb could damage the solar panel.

Please stress to students: Large-solar panel arrays, just like other power sources, can produce great amounts of electricity. They should **never** experiment with electricity from any source without adult supervision and **never** experiment with electricity from a wall outlet. Classroom exploration of electricity is safe as long as small solar panels or low-voltage batteries are used and a teacher supervises activities.

- Applaud all groups for their successful experimentation and inform them that they have just used radiant energy from the sun to power a motor. This is very similar to the way electricity is generated on the ISS. On Earth, many homes and businesses also are powered by solar energy.
- Have students create illustrations of the electrical circuit they have created to transfer energy from the sun to the motor and label its parts.

Extending Experience

Set aside some time for students to take turns during further investigations with the solar-powered kit. After learning how to transfer energy to the motor, students will enjoy using the parts supplied in the kit to create machines with moving parts.

Teacher Tip

Assessing Group Work

Base assessment of student performance in group work on your observations of participation in teams, including:

- following directions
- sharing equipment
- participating in discussion
- recording and comparing data
- contributing ideas, and
- completing student lab sheets

Individual student performance can be based on the number and quality of illustrations, ideas, and questions recorded in the student's logbook.

Lesson 2: Living in Outer Space

In this lesson, students will investigate how astronauts live in microgravity on the International Space Station and compare conditions there to those on Earth. They will consider what is needed on the space station to sustain life, including air, food, water, and exercise. They develop an understanding of the ISS as a closed life-support system and construct a closed-system model to test their ideas.

Above: Nine of a total of 13 astronauts and cosmonauts gather at meal time aboard the International Space Station. Normally, only 6 people at a time live on the ISS. (July 21, 2009)
PHOTO CREDIT: NASA

Focus Questions

- What is needed to sustain human life in any environment?
- How is living in a microgravity environment similar to and different from living on Earth?
- How do astronauts meet their needs for food and water?
- What foods are best suited for long-term living in microgravity?
- How are foods prepared for consumption in space?
- What can we do to preserve food for long-term life in space?
- How does microgravity affect an astronaut's body?
- Why is physical training before, during, and after a spaceflight important?
- What are some ways to maintain a healthy body on long-term spaceflights?
- How have humans engineered ways to live in space?

Objectives

Students will

- identify the basic conditions required to sustain human life
- examine the challenges microgravity presents to the daily activities and health of astronauts
- explain how foods are selected and prepared for the ISS
- investigate ways of preserving foods and explain why **dehydration** is a good way to prepare and store food for long-term space missions
- examine the characteristics of a **closed system** and build a **prototype** of a **biodome**
- carry out tests to explain how exercise helps the human body reduce the effects of microgravity

Vocabulary

biodome
closed system
dehydration
fluids
hydration
irradiated
prototype
rehydration
thermostablized

Above: Astronaut Donald R. Pettit, Expedition 6 NASA ISS science officer, exercises on the Cycle Ergometer with Vibration Isolation System (CEVIS) in the Destiny laboratory on the ISS. (January 2, 2003) PHOTO CREDIT: NASA

You will need

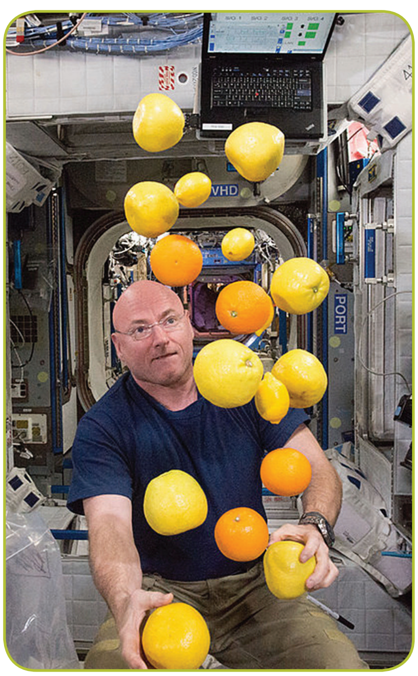
Experience 1: Foods in Flight

1 or 2 class periods

- ❏ Photos of space food from early and recent flights
- ❏ Samples of both fresh and dehydrated fruits and vegetables
- ❏ Examples of canned and frozen fruits and vegetables

Experimental materials:

- ❏ Resealable plastic sandwich bags
- ❏ 4 or 5 black markers
- ❏ Dried fruit, such as apple slices, 6 slices per team (found in the bulk foods section in most grocery stores)
- ❏ water
- ❏ measuring cup
- ❏ digital scale
- ❏ tongs or large tweezers
- ❏ Student Lab Sheet, page 34
- ❏ crew logbooks



Above: Astronaut Scott Kelly after a cargo delivery of fresh fruits and vegetables.
PHOTO CREDIT: NASA

Experience 2: Closed Systems

1 or 2 class periods

- ❏ 2 clear 2-liter soda bottles or 1 large, clear glass jar with lid per team
- ❏ organic potting soil
- ❏ small stones
- ❏ sharp scissors
- ❏ small plants
- ❏ activated charcoal
- ❏ permanent marker
- ❏ water
- ❏ crew logbooks

Experience 3: Staying Fit

1 or 2 class periods

- ❏ **NASA** video *A Day in the Life Aboard the ISS* (see **Resources** section)

Equipment for 3 experimental exercise stations:

- ❏ 3 stopwatches (check with the athletic department at your school)
- ❏ 3 electronic fitness monitors or other devices for measuring heart rate
- ❏ Equipment to be determined with help of physical education teacher, such as:
  - Resistance bands, small weights, or plastic bottles filled with water
  - A simulated treadmill (two chairs with backs toward student as he or she walks in place)
  - Aerobic exercise device (stationary bike, jump rope, or space for dancing or movement)
  - Student Lab Sheet, page 40

Academic Standards

Indiana Academic Science Standards (2016)

K–12 Science/Engineering Process Standards

SEPS.1, SEPS.2, SEPS.3, SEPS.4, SEPS.5

Engineering

3-5.E.2, 3-5.E.3

Life Science

6.LS.1

Next Generation Science Standards

3-5-ETS1-2, 3-5-ETS1-3; 4-LS-1; 5-LS-1; MS-LS2-4

Above: Students react to food shrinking in a vacuum chamber during a Science, Technology, Engineering, and Math (STEM) education event held in Arlington, Virginia. (January 19, 2013) PHOTO CREDIT: NASA/BILL INGALLS

Experience 1: Foods in Flight

In this experience, students examine images and descriptions of space food to determine why food is specially prepared for astronauts and discuss different ways of preserving food for long-term spaceflights. Then students will carry out an investigation demonstrating what happens when foods are dehydrated and hydrated. They calculate the weight differences in dehydrated and hydrated foods and determine if these differences would be significant in terms of the cost of resupplying and storing food for the ISS.

Above: European Space Agency astronaut Luca Parmitano, Expedition 36 flight engineer, with food packages floating freely in the Unity module of the ISS. (June 24, 2013) PHOTO CREDIT: NASA

Procedures

- Have students make a brief list of foods they like to pack for a picnic and record in the crew logbook. Briefly share the selections as a crew.
- Ask student what they think astronauts eat while they are aboard the ISS. Are they able to take the foods they like with them? What would be some of the problems astronauts might have eating in a microgravity environment? How would you eat a bowl of soup? What about ice cream?
- Explain that in the early days of spaceflight astronauts had very limited choices.
- Show students a photo of food from early spaceflights (1960s). Ask: What do you notice? Would you want to eat food from a tube? Why was that necessary?
- Students have identified problems with microgravity as one reason foods for spaceflights have to be especially prepared. Ask if there are other problems as well.
- Remind students that they are about to travel to the ISS by rocket and it will be necessary to live in space for at least six months. Ask: How can you keep food from spoiling?

Early Space Food

When spaceflights began in the 1960s, food for astronauts was packaged as a freeze-dried powder, in tiny cubes, or as a paste that was squeezed out of a tube. Recently, NASA food engineers have developed meals for astronauts that are similar to ones they enjoy on Earth. Today, before a flight, astronauts can select from more than 200 items on the ISS menu.

Food for spaceflights is packaged and served differently than it is on Earth. In microgravity, astronauts must be careful that foods don't leave crumbs or other residue because in microgravity, food particles can become lodged in ISS equipment and vents. Most foods for the ISS are dehydrated by freeze drying before a spaceflight to make them lighter and less likely to spoil. Drinks and soups are packed as powder and rehydrated with water while in orbit. Meals must be rehydrated and heated. Then they can be eaten right out of the package because the food was cooked on Earth and vacuum-sealed prior to launch.

For more information, see nasa.gov/audience/forstudents/postsecondary/features/F_Food_for_Space_Flight.html and nasa.gov/audience/foreducators/stem-on-station/ditl_eating

Above: Early space food from the Mercury and Gemini missions (1961–1969), including meals served in toothpaste-style aluminum tubes and gelatin-covered cubes. PHOTO CREDIT: NASA

- Discuss the way foods are preserved on Earth. Are there reasons why some of these solutions might not work in space?
- Ask students if they remember packing their personal items for the flight. What were the limitations on the number and kind of items they could take? Why?
- Remind students of their discoveries in Lesson 1, where they experimented with launching balls of different weights. They learned that it takes more force to launch an object that has more mass (volume and weight). (See Newton's Second Law of Motion on page 16.)
- Ask: What does this mean if you are trying to launch a rocket with cargo (including a supply of food) for the ISS? Students will probably respond that it is easier to launch cargo that is lighter (has less mass).
- Explain that this is the reason rocket engineers try to make the cargo as light as possible. It takes less force and less fuel energy to launch a lighter load. Available space aboard the rocket and on the ISS is also a problem. So decreasing the volume of the cargo is important.
- Have students suggest solutions: What would you do to lighten the cargo? How would you make foods for the ISS light, compact, nutritious, and resistant to spoiling?
- Present students with examples of fresh fruits and vegetables. (Students should have opportunities to sample the fresh foods. Be sure to check for allergies first.)
- Explain that astronauts today do have access to some fresh foods but the amount is limited. Why? Students will probably observe that it takes up a lot of room and will spoil in a few days.

PHOTO CREDIT: NASA

Space Food Today

NASA currently uses seven classifications for space food:

- **Beverages** – dehydrated
- **Fresh Foods** – foods with a 2-day shelf life such as fresh fruit
- **Irradiated Meat** – preserved with a technology of ionizing radiation to keep food from spoiling (this option is not used very much)
- **Intermediate Moisture** – foods that have less water so they won't spoil as soon as fresh foods, such as dried fruit like apricots and raisins
- **Natural Form** – foods that don't require treatment, such as nuts, cookies, granola bars, condiments (catsup, mustard, pesto, jelly, and garlic paste, packaged in squeeze bottles and refrigerated)
- **Rehydratable** – water is removed from foods on Earth and added before eating in space
- **Thermostabilized** – food that has been prepared with heat to kill bacteria or other possible spoiling agents

- Present students with examples of packaged frozen foods and canned foods. Ask about advantages and disadvantages of using these foods in space.
- Ask students if they have ever eaten a dehydrated food. **Dehydration** is the process of removing water from food. Have they ever had raisins or a powdered drink?
- Provide a selection of dehydrated vegetables and fruits, including apple slices. Encourage students to sample them and compare the taste and texture with the fresh foods they have tried.
- Ask students: Do you think these foods would be nutritious? Could you store them without refrigeration? Are they light enough to launch into orbit?
- Explain that students are going to experiment with hydrated and dehydrated foods to see which would work best in space. What are their predictions?
- Describe how students will rehydrate (replace the water) a sample of dried fruit and compare the weight before and after.

- Place students in teams of 3 or 4 and provide each team with 6 dried apple slices, 2 resealable plastic sandwich bags, 1 marker pen, and the Student Lab Sheet **An Apple a Day** on page 34.
- Have each student team label the bags with their team number or name and then place 4 apple slices in one bag and label it with "E" for the **experimental sample** and 2 slices in the other bag labeled "C" for **control**. (It is not necessary for the experimental and control bags to have the same number of apple slices.)
- Set up a weigh station with a digital scale, tongs or tweezers, additional plastic bags, and paper towels in case of spills.
- To begin the experiment, have teams take turns using the digital scale to carefully weigh their experimental samples in the bags and use the Student Lab Sheet to record the weight in grams. They should also weigh and record the control samples and make observations about the appearance of the apples in both bags.
- After recording the preliminary data and observations, have each team use the measuring cup to pour enough water (**experimental treatment**) into sample bag "E" to completely cover the apple slices. Explain that the apple slices are not uniform in size and weight so all samples will have different weights. The goal of the experiment is to determine the weight difference in each team's experimental sample after the apple slices absorb water over a period of time.
- Make sure the bags are completely sealed and stored in a safe place. After 24 hours, have each team use the tongs or tweezers to carefully remove the experimental apple slices from the bag without spilling the water, place them in a clean bag,weigh the apple slices, record the data, and return the apple slices to the original bag.
- After two more days, repeat the data collection process. Ask teams to carefully examine both the experimental and control samples and record their observations.
- Ask students about the appearance of the apple slices. Did the experimental samples begin to look more like fresh apple slices in some ways? Which samples would be likely to spoil first, the hydrated apples or the dehydrated apples?
- Discuss the teams' findings as a large group. Were there changes in the weight of the experimental samples? How much? Were there changes in the control samples?
- Ask students if they think the changes in weight they recorded are significant. Would using dehydrated food for spaceflights make a difference? Why or why not?
- Remind students that spaceflights may last for six months or more. Have each team consider that three astronauts on the ISS might eat four dehydrated apple slices a day every day for six months.
- Ask: Based on the results of your experiment, approximately how many grams of dehydrated apple would that be? How many kilos would that be? What would be the total weight if the astronauts were eating hydrated or fresh apple slices?
- Ask students which would require more energy to transport to the ISS: a six-month supply of hydrated apple slices or a six-month supply of dehydrated apple slices. Ask: When you think about the weight of the amount needed, does it make sense to use dehydrated foods on the ISS?
- Have students use their logbooks to record and explain their conclusions.

Extending Experiences

- If you have access to a food dehydrator, have students carry out an experiment weighing and comparing fresh fruits and vegetables before and after dehydration.
- Conduct an experiment to see if dehydration prevents food from spoiling. Put a fresh apple slice, a rehydrated apple slice, and dehydrated apple slice in separate plastic bags and leave at room temperature for several days. Then ask students: Which apple slice would you want to eat? What role does moisture play in food spoilage?

STUDENT HANDOUT

STUDENT LAB SHEET: AN APPLE A DAY

Team Name or Number: ____

Measurement 1 (before rehydration)			
SAMPLE	DATE	WEIGHT (grams)	OBSERVATIONS
Sample E			
Sample C			

Measurement 2 (during rehydration)			
SAMPLE	DATE	WEIGHT (grams)	OBSERVATIONS
Sample E			
Sample C			

Measurement 3 (after rehydration)			
SAMPLE	DATE	WEIGHT (grams)	OBSERVATIONS
Sample E			
Sample C			

Experience 2: Life Support

Life in orbit is not natural for human beings. We need specific things to survive that do not exist in the upper atmosphere where the ISS orbits the Earth. These things must be transported to the ISS or produced on board. Scientists have designed the International Space Station to make it as self-sustaining as possible. It is a partly closed system, although it needs occasional resupply of some necessities, like food. In this experience, students will build a terrarium as a model of a closed system and explore the needs of a closed life-support system in space.

Above: NASA astronaut Rick Mastracchio, Expedition 38 flight engineer, prepares to use ultraviolet light to decontaminate hardware, which will be used for life science experiments inside the Microgravity Science Glovebox (MSG). (Feb. 10, 2014) PHOTO CREDIT: NASA

Ahead of class:

- Wash and remove labels from two 2-liter plastic bottles per team or use 1 large, clear glass jar with lid per team.
- If using plastic bottles, draw a line around each bottle about 15 cm (6") from the bottom.
- Each team will need two bottom sections from the plastic bottles.
- Cut along the line with a pair of scissors or box cutter. A parent or other volunteer might help prepare the bottles.

Procedures

- Place students in think-pair-share teams to continue to explore the question "What do human beings need to survive both on Earth and in space?" Students will probably list food, water, air, light, shelter, and temperature control.
- Have students think about life on the ISS and sort the list into three categories: things that need to be 1) built or created, 2) provided, and 3) disposed of such as waste. Give students time to brainstorm possible solutions.
- As a class, discuss students' ideas and what they have learned so far about the ISS and its life-support systems. Ask: Do you think it is possible that some of these needs can be met aboard the ISS and not brought in from outside?

Recycling and Reclaiming on the ISS

NASA's life-support engineers have developed air and water recovery systems that "reclaim" water and oxygen for the ISS and future space explorations by combining or breaking down the byproducts of other processes. An oxygen generation system creates breathable oxygen from the carbon dioxide and water that are byproducts of human respiration. The water recovery system recycles wastewater and the crews' urine to create a fresh supply of drinkable water. This helps create a closed-loop life-support system necessary to sustain ISS crews as they continue their research on longer missions to the moon and even other planets.

For more information, watch NASA videos Recycling on the ISS (Grades K–5), Home Improvement—Space Station Style (Grades 6–8), and Environmental Control on the ISS (Grades 6–8).

Above: Zinnia flowers are starting to grow in the International Space Station's Veggie facility as part of the VEG-01 investigation. Veggie provides lighting and nutrient supply for plants in the form of a low-cost growth chamber and planting "pillows" to provide nutrients for the root system. PHOTO CREDIT: NASA

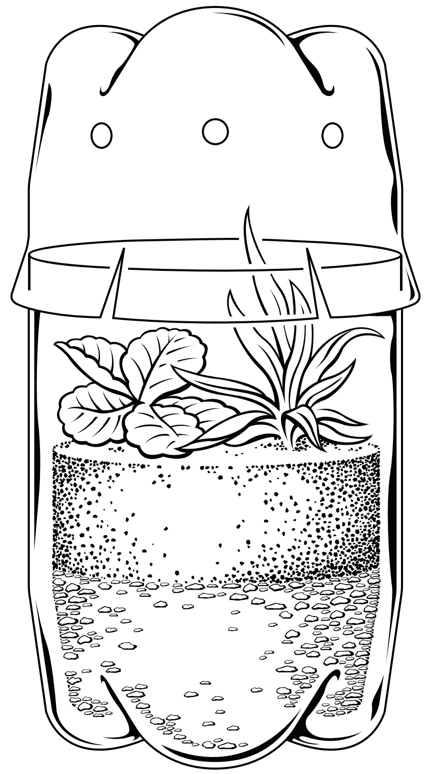
Above: Commander Scott Kelly tweeted photos of the first-ever space flowers, zinnias, which bloomed on Jan. 16, 2016. PHOTO CREDIT: NASA

- Ask students if they know what a **closed system** is. Help them understand that a closed system is a system that does not interact with the environment outside of it. A closed system does not exchange any matter with its external surroundings.
- Ask students if they think the ISS is a closed system. Why or why not? What challenges would such an environment present? What advantages could it have?
- Explain to students that they are going to create a terrarium, which is one type of closed ecosystem, to better understand what a closed system is and how it works. This terrarium will be home for a small plant.
- First, have students think about what a plant needs to survive. Answers should include things like soil, water, air, and light.
- Next, divide the class into teams of 3 or 4 students. Each team should receive the bottom sections from two prepared 2-liter drink bottles (or a large, clear glass jar with lid).

Teacher Tip

To make a straight line around a soda bottle, use a marker to make indications in four to six spots at about 15 cm (6") from the bottom, in order to guide cutting. You can even line up the marks with a piece of masking tape wrapped around the bottle. To help fit the two bottle pieces back together again, cut a vertical slit about 2.5 cm (1") on one side of the bottom piece. Then you can squeeze the bottom a little to make it fit inside the top.

- Provide supplies and have teams follow the construction instructions:
  - Sprinkle small stones in a 4 cm (about 1.5") layer in the bottom of the bottle.
  - Add a small layer of charcoal on top of the stones.
  - Layer soil on top of the charcoal, and then add soil to about 2.5 cm (1") from the top.
  - Make a small hole in the soil. Insert a small plant in the soil and completely cover its roots with soil.
  - Sprinkle enough water into the container to moisten the soil. Do not overwater.
  - Place the bottom section with the vertical slits so that it covers the outside of the other section (see illustration).



- Explain to students that they have created a **terrarium** and explain the meaning of the word. Ask students if there is anything missing from their terrarium that plants need to survive. The only thing the plants will need from outside the closed system is energy from sunlight! Have teams place their terrariums near a window for bright but indirect sunlight, or under a lamp.
- Observe terrariums carefully during the first week and make adjustments to the amount of water and light if necessary.
- Teams should observe the terrarium using a magnifying lens for several weeks and record or illustrate in the Crew Logbook all planting steps and any growth or changes once a week.

- After several weeks, ask students what they have learned about closed life-support systems through the creation and observation of their terrariums.
- Discuss with students what they have discovered from their observations. What role did each component within the terrarium play in recreating the environment?
- Students will probably observe that the stones and charcoal provide drainage so that the roots do not get too wet. The soil gives the plant nutrients and a place to grow.
- Discuss the different parts of the plant and how they interact with the environment to meet the plant's nutritional needs and help maintain the balance needed.
- Ask students to use their crew logbooks to illustrate and label the water cycle inside the terrarium as it goes through a process of respira-tion, evaporation, and condensation, giving the plant enough water to survive for some time without having to open it to add more.
- Encourage students to think more about what humans need to survive. Point out that just as the terrarium is closed off from the world outside, the ISS also is closed off from the dangerous upper atmosphere and is distant from the Earth's surface. What is needed to survive in the closed system of the ISS?
- Remind students that although there are occasional resupply opportunities, for the most part astronauts living on the ISS must have everything they need to survive available and contained within the closed environment of the ISS and with them at liftoff.
- Help students generate a list of life support needs on the ISS and brainstorm ways to satisfy these needs in orbit. They should record ideas and questions in their logbooks for future reference.

Above: After NASA's Mission Control gave the Expedition 19 astronaut crew aboard the International Space Station a "go" to drink water that the station's recycling system had purified, the three celebrated with a toast. (May 20, 2009) PHOTO CREDIT: NASA

Extending experiences

Have students:

- Create different ecosystems using different containers, soils, plants, and moisture, and research current biodome experiments around the world.
- Explore the NASA website to learn how engineers are recycling and reclaiming water and air to create a closed-loop life-support system on the ISS.
- Search the web to discover how scientists are experimenting with plants to see if they can be grown in space. While it is not practical to grow a sufficient number of plants to regenerate oxygen and water on the ISS, growing plants in space will provide information that may help improve life on Earth. Studying plants in space also may be important for life support in future explorations.

Above: Dr. Matthew Mickens, a plant biologist from North Carolina Agriculture and Technical State University, measures Cherry Bomb Hybrid II radish plants harvested from a plant growth chamber inside the Space Life Sciences Laboratory at NASA's Kennedy Space Center.
PHOTO CREDIT: NASA/FRANK OCHOA-GONZALES

Experience 3: Staying Fit

Students learn how astronauts living in space have to work to remain healthy. Students examine the effects of microgravity on the human body and learn how astronauts exercise before and during spaceflights to counteract these effects. Students monitor the effect of exercise on their own bodies, explain why this is necessary for good health, and create a daily exercise program for an astronaut in space.

Above: Astronaut Edward T. Lu, Expedition 7 NASA ISS science officer and flight engineer, uses the short bar for the Interim Resistive Exercise Device (IRED) to perform upper body strengthening pull-ups. PHOTO CREDIT: NASA

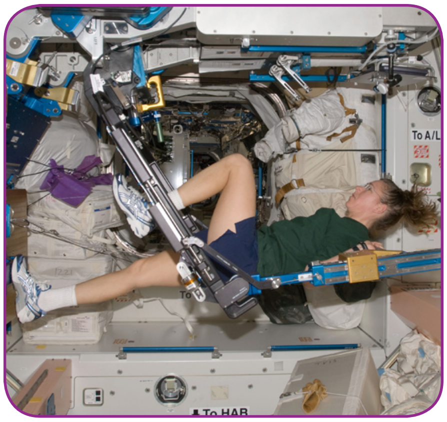
Preparation

Before beginning this experience, work with the physical education teacher to plan three experimental exercise stations. The exercise activities chosen should use a minimum of equipment, be age-appropriate, and have suitable adaptations for students with special needs. Stations should reflect the three types of strength training used on the ISS: 1) lower-body exercise (treadmill), such as marching or walking in place; 2) general muscle building (weight lifting), such as the large rubber resistance bands found where yoga equipment is sold; and 3) an aerobic exercise (stationary bike), such as jumping rope, dancing, or other body movements that will increase the heart rate. If possible, plan to do the experience outside or in the school gym.

Procedures

- Ask students to watch videos from *A Day in the Life Aboard the International Space Station* on the NASA website (nasa.gov/audience/foreducators/stem-on-station/dayinthelife) and focus on how astronauts move and use their bodies in microgravity. While this looks like fun, astronauts have to train their bodies to function in space.
- Ask students to suggest how low gravity might affect the way an astronaut's body works.
- Some students may observe that in microgravity astronauts are using their muscles less.
- Have students imagine what it would be like to lift things with no effort or to be able to move from one side of the room to the other in a single leap.
- Ask: Is this a good thing? What happens when we use our muscles less? Students will probably suggest that muscles will become weaker.
- Explain that, in fact, the work gravity causes us to do is good for our bodies. If they are not used, both bones and muscles lose strength. Loss of bone and muscle would not be good for the long-term health of astronauts when they return to Earth.

Above: With the help of bungee cords to hold her in place, astronaut Suni Williams jogs on the Treadmill Vibration Isolation System aboard the International Space Station. PHOTO CREDIT: NASA



Above: Astronaut Sandra Magnus, Expedition 18 flight engineer, exercises on the advanced Resistive Exercise Device (aRED) in the Unity node of the ISS. PHOTO CREDIT: NASA

- Ask students if their hands or feet have ever felt swollen after standing in line for a long time. What does gravity have to do with this?
- Explain that about 60% of the body is made up of fluids. On Earth, gravity causes most of the body's fluids to be distributed below the heart. The heart works to pump blood through the body's circulatory system. On Earth, exercise helps the heart grow stronger.
- Ask: How do you think microgravity will affect the heart, one of the most important muscles in the body?
- Explain that since the heart doesn't have to work as hard in microgravity it loses muscle mass and gradually becomes weaker. Like all the other muscles, it needs exercise to become and remain strong.
- Visit *A Day in the Life Aboard the International Space Station* on the NASA website. Have students view the fitness videos with Sunita Williams and Michael Lopez-Alegria (nasa.gov/audience/foreducators/diypodcast/fn-video-index-diy.html#.V2Gf5q7eTQw).
- As they watch, they should use their logbooks to take notes on the kinds of exercise equipment astronauts use and how long they exercise every day.
- Follow up by discussing why different types of exercise are important and why equipment has to be especially designed for the ISS. Ask: Why do astronauts have to train their bodies before, during, and after a space mission?
- Tell students they will have the opportunity to test some exercise activities to determine if they would be useful in training astronauts for spaceflight. They will work in groups and will need to record data accurately.
- Place students in teams of 3 or 4 and provide the Student Lab Sheet on page 40. At each station, students will use the stopwatch to help each other measure heart rates before and after performing the exercise for two minutes.
- After completing the exercises, ask the teams to compare their data. Which exercise would be best to strengthen the heart? Why? Which exercise would build muscles in the upper body? Which exercise would strengthen the muscles and bones in the lower body?

Assessment: Crew Logbook

Astronauts begin training and working out long before their scheduled spaceflight. Have students use their logbooks to plan their individual exercise routine on Earth as they train to become astronauts on the ISS. Students should remember to include at least three different types of exercise: one to strengthen the heart, one to strengthen the muscles and bones in the upper body, and one that will strengthen the lower body. They should also be able to explain why it is important to do different types of exercises and why training before, during, and after a mission is important for astronauts' health.

Above: Working under water helps astronauts prepare for spacewalks. This photo shows a diver assisting astronauts in an underwater tank with the Hubble Space Telescope simulator at NASA's Johnson Space Center in Houston, Texas. PHOTO CREDIT: NASA

STUDENT HANDOUT

STUDENT LAB SHEET: BUILDING STRENGTH FOR SPACE

Team #: ____

Student Name: ____

Exercise Station Number	Type of Exercise LB, GM, or AE	Heart Rate after 2 minutes

Type of Exercise Key
LB = Lower Body Exercise
GM = General Muscle Building
AE = Aerobic Exercise

Observations: ____

____

____

____

____

____

____

____

____

____

____

____

Lesson 3: Working in Outer Space

In this lesson, students consult the NASA website to learn more about science research in space. They carry out an experiment growing crystals and explain the importance of the research astronauts are conducting with crystalline substances in microgravity on the International Space Station. They learn about the work astronauts do to maintain, repair, and upgrade the space station and, in a culminating experience, design and build a 3D model of a tool, a module, or other equipment for use on the ISS.

Above: Astronaut Reid Wiseman installs Capillary Channel Flow (CCF) experiment hardware in the Microgravity Science Glovebox located in the Destiny laboratory of the ISS. PHOTO CREDIT: NASA

Objectives

Students will

- identify science research projects being planned and carried out on the ISS and explain how this research is important for future space exploration and for living on Earth
- carry out an experiment to grow crystals and document the results
- explain why scientists are conducting research on the behavior of different materials in microgravity
- identify the dangers of working in space and describe how special equipment is designed to protect astronauts
- follow the engineering design process and work in teams to create a space station module or tool and present it to an audience
- develop a proposal for research on an idea, substance, or tool that they would like to test on the ISS

Vocabulary

crystalline substance

EVA (Extravehicular Activity)

prototype

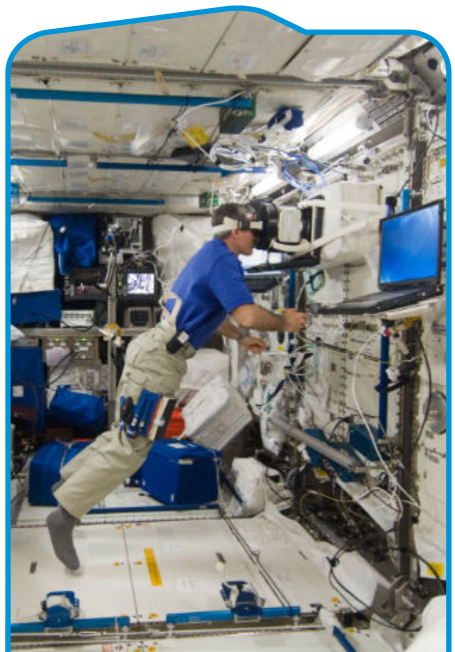
tether

simulation

solution

Focus Questions

- What are crystals and how are they used? Why are they being used in space science experiments?
- What are the unique benefits of conducting science research in space?
- Why do astronauts need special equipment and tools to work in space?
- Why are simulations and training important for astronauts?
- What steps do scientists and engineers use to develop and test new ideas and products?



Above: Expedition 30 Commander Dan Burbank uses Neurospat hardware to perform a science session with the PASSAGES experiment in the Columbus laboratory. PHOTO CREDIT: NASA

You will need

Experience 1: It's Crystal Clear

2 class periods

- ❑ access to NASA website (nasa.gov)

For each team:

- ❑ 1 wide-mouth jar or beaker
- ❑ 2 labels for each jar
- ❑ pipe cleaner
- ❑ stick or pencil
- ❑ borax (washing soda)
- ❑ boiling water
- ❑ measuring tablespoon
- ❑ long-handled spoon for stirring solution
- ❑ paper towels
- ❑ magnifying lens
- ❑ Experiment Instructions, page 45
- ❑ food coloring (optional)

For each student:

- ❑ safety goggles
- ❑ Student Lab Sheet, page 46
- ❑ crew logbook

Experience 2: Tools of the Trade

2 class periods

- ❑ photos of astronaut suits
- ❑ clock or stopwatch
- ❑ 4 pairs heavy work gloves
- ❑ 8 carabiners for 4 tethers
- ❑ 1 wrench tethered to 1 meter of rope
- ❑ 4 lengths of rope, each 1 meter
- ❑ Assorted nuts, bolts, and washers
- ❑ 4 supply boxes (tool boxes)
- ❑ crew logbook

Experience 3: Rise to the Challenge

2 class periods

- ❑ flipchart or poster paper
- ❑ markers
- ❑ modeling clay and other materials for 3D models
- ❑ crew logbook

Academic Standards

Indiana Academic Standards for Science 2016

K–12 Science/Engineering Process Standards
SEPS.1, SEPS.2, SEPS.3, SEPS.4, SEPS.6, SEPS.8

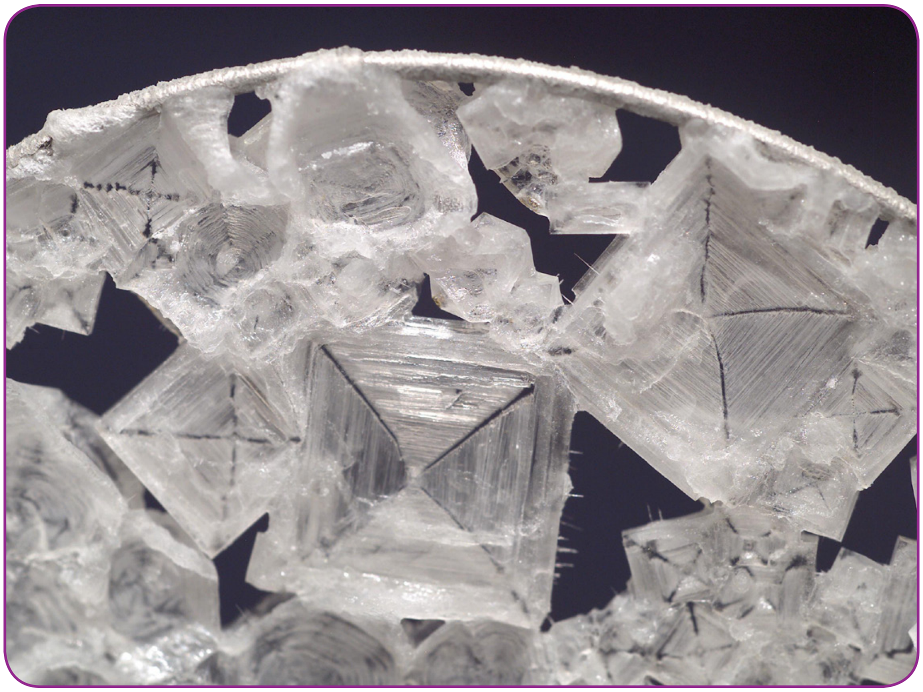
Engineering
6-8.E.1, 6-8.E.2, 6-8.E.3, 6-8.E.4

National Standards

Next Generation Science Standards

Matter and Its Interactions
MS-PS1-1

Engineering Design
3-5-ETS1-1, 3-5-ETS1-2, 3-5-ETS1-3; MS-ETS1-1, MS-ETS1-3, MS-ETS1-4



Experience 1: It's Crystal Clear

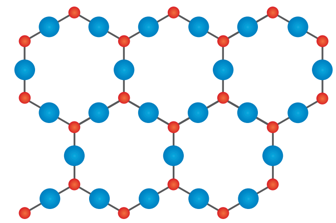
In this experience students learn that one of the major functions of the ISS is to serve as a laboratory where astronauts carry out experiments planned by scientists to discover how both living and nonliving things react to microgravity. One important experiment involves growing crystals on board the space station. To better understand the significance of these experiments, students simulate the process of growing crystals in different environments in the classroom.

Above: Looking for all the world like a snowflake, this is actually a close up view of sodium chloride crystals. The crystals are in a water bubble within a 50-millimeter metal loop that was part of an experiment in the Destiny laboratory aboard the International Space Station and was photographed by the Expedition 6 crew. PHOTO CREDIT: NASA

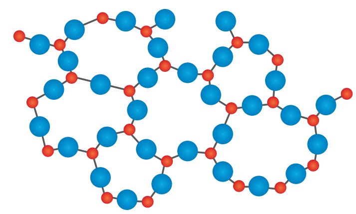
Procedure

- Remind students that if they were the crew of the International Space Station, they would be working in a space science lab, operating in microgravity. Explain that some of the experiments they would carry out might involve substances called crystals.
- Ask: What is a crystal? Students may have difficulty arriving at an answer since many things referred to as "crystal" are not **crystalline substances** at all.
- Show students some examples of common crystalline substances we use every day, such as salt and sugar, and allow them to examine the substances with a magnifying lens.
- Explain that quartz and diamonds used to make jewelry are crystals. Crystals are used in electronics and even in medicines. Some forms of protein crystals help provide the building blocks for our bodies. Other crystals can actually play a role in causing diseases.
- Ask students why they think scientists would be interested in studying crystals in microgravity.

Use students' answers to emphasize that crystals are important in manufacturing products and medicines, so scientists want to find out if crystals can be grown in space.



Crystal Structure

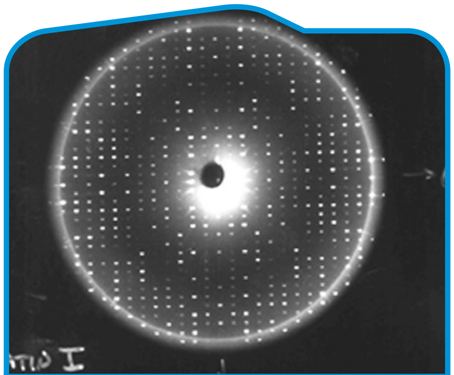


Glass Structure

What Is a Crystal?

Many solid materials are crystalline substances. This means their molecules group together in a highly organized repeating structure. These materials include common household materials like salt, sugar, baking soda, and the graphite used in pencils as well as more precious materials, such as diamonds. While water is not a crystal in its liquid state, it becomes a crystalline substance in the form of frost, snowflakes, and ice at temperatures below 0°C (32°F).

Students may have the misconception that glass is crystal. In fact, glass is not a crystalline substance because its molecules do not group together in a regular, repeating pattern. Scientists consider it to be an amorphous solid because of its irregular molecular organization. The type of glass called "lead crystal" or "crystal glass" is simply glass with substances added that cause it to refract light and sparkle.



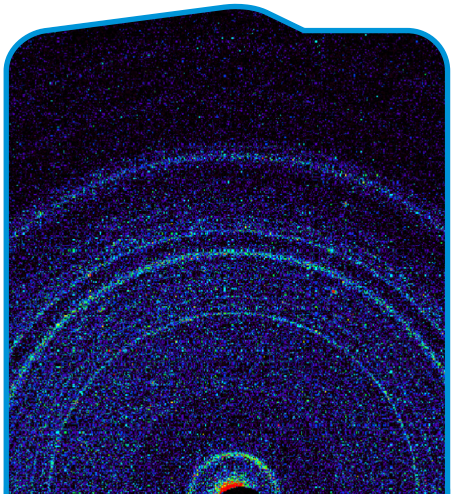
Crystals in Space

Most new medicines are designed by using special protein crystals. To understand how a protein works, scientists must study its structure carefully using X-ray crystallography. This allows them to create compounds that will bind to the protein. This can be difficult due to the complex structure of protein molecules.

Growing some protein crystals for medical research on Earth can be almost impossible, because gravity causes crystal molecules to settle on top of each other, creating structural flaws. As a result of experiments done on the ISS, however, scientists have discovered that they can grow larger, more perfectly formed crystals in microgravity. Using protein crystals produced in low gravity, scientists have already developed a more effective form of insulin, used to help people with diabetes. This is one example of how scientific experiments in space are improving life on Earth.

Above: X-rays diffracted from a well-ordered protein crystal create sharp patterns of scattered light on film. A computer can use these patterns to generate a model of a protein molecule. To analyze the selected crystal, an X-ray crystallographer shines X-rays through the crystal. PHOTO CREDIT: NASA

Above: The Martian soil examined shows the diffraction signature, or "fingerprint," of the mineral olivine, shown here on Earth in the form of tumbled crystals about a quarter-inch (several millimeters) in size. The semi-precious gem peridot is a variety of olivine. PHOTO CREDIT: NASA



Above: The first X-ray crystallography view of Martian soil obtained by the Chemistry and Mineralogy (CheMin) experiment on NASA's Curiosity rover. This data reveals crystalline feldspar, pyroxenes and olivine mixed with some amorphous (non-crystalline) material. The soil sample is similar to volcanic soils in Hawaii. PHOTO CREDIT: NASA

- Tell students they will conduct a **simulation** of the astronauts' work by growing their own crystals in different environments in the classroom.
- Divide the crew into teams of 3 or 4. Provide each team with experimentation equipment including: 1 jar, labels, 1 pipe cleaner, pencil, tablespoon, stirring spoon, paper towels, and magnifying lens. Review the Experiment Instructions and discuss how to work together as a team.
- Establish four environments, such as **A:** Daylight/night–window, **B:** Dark–closet, **C:** Cold–refrigerator or cooler, **D:** Heat–near a heat source. Each should have room for 2 or 3 jars. Assign specific teams to each environment. Make sure teams label their jars **A**, **B**, **C**, or **D**.
- **Follow up Discussion:** After students complete the experiment, ask: How did each environment affect the way the crystals grew? What environment(s) might be the best for growing crystals? Why? What other kind of crystal growing environments could be created in the classroom?

STUDENT HANDOUT

LAB SHEET – CRYSTAL GROWING EXPERIMENT

Team name or number: ____

INSTRUCTIONS

1. Shape a pipe cleaner so it has a loop on one end that fits securely around a stick or pencil.
2. Position the stick across the top of the jar. Dangle the pipe cleaner into the jar so it is not touching the bottom.
3. Ask the teacher to pour hot water into the jar. Make sure the pipe cleaner is thoroughly saturated.
4. When the pipe cleaner is wet, temporarily remove it from the jar and set it aside on a piece of paper towel.
5. Wearing goggles, carefully measure and add 3 tablespoons of borax. Take turns stirring the liquid until the borax is completely dissolved and a **solution** is formed.
6. Gently reposition the stick on the jar's rim so the pipe cleaner dangles down into the solution.
7. As the experiment begins, examine the jar and draw your observations on your **Crystal Clear Lab Sheet**. Visit other teams and record your observations.
8. After jars have cooled, carefully place your team's jar in its experimental environment. Be sure to label the jar **A**, **B**, **C**, or **D**.
9. After 24 hours, make careful observations of your team's jar. Pull the pipe cleaner out and hang to dry. Label the pencil or stick **A**, **B**, **C**, or **D**.
10. Use a magnifying lens to examine the crystal growth on your team's pipe cleaner. Label it **A**, **B**, **C**, or **D**..
11. Carefully examine pipe cleaners and jars from each growing environment and document your observations on the **Crystal Clear Lab Sheet**.

Teacher Tip

Use caution with borax. With younger students, an adult should measure the borax and add the hot water to the jar. Students should wear goggles and be careful not to splash the borax solution while stirring. Add food coloring to the borax solution for colored crystals.

To extend the experience, try growing crystals on different surfaces, such as a large nail, a chain of paperclips, a wooden stick, or a piece of fishing line.

STUDENT LAB SHEET

CRYSTAL CLEAR

Student Name: ____

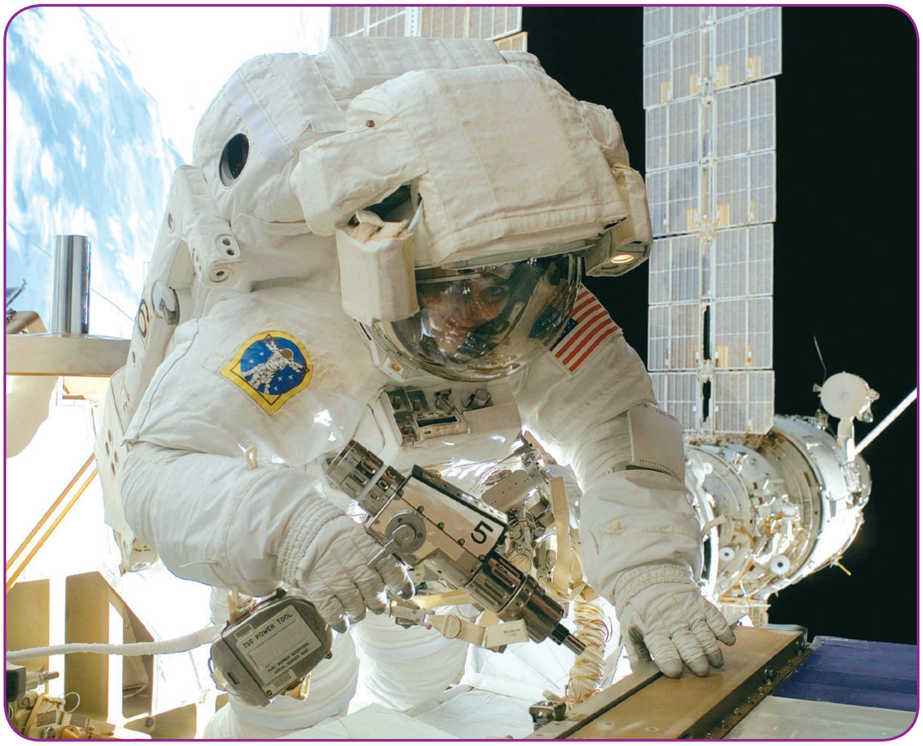
1. **Illustrate a jar in each crystal growing environment before the experiment.**

A	B	C	D
daylight	dark	cold	warm

24 hours later:

2. **Illustrate a jar in each crystal growing environment after the experiment and show any changes.**

A	B	C	D
daylight	dark	cold	warm



Experience 2: Tools of the Trade

In this experience, students simulate the difficulty of working in space by completing tasks while wearing gloves and using tethered tools. They examine spacesuits to identify the features that allow astronauts to work outside of the ISS. They also learn how astronauts work together as a team and depend on each other as well as on their equipment for safety.

Above: Astronaut Sunita L. Williams, Expedition 14 flight engineer, uses a pistol grip tool as she works on the International Space Station in the first of three spacewalks. PHOTO CREDIT: NASA

PHOTO CREDIT: NASA

Designed for Space

Amy Ross is credited with designing shuttle spacesuit gloves, launch and entry suit gloves, and STS-100 EVA tools. She earned bachelor's and master's degrees in mechanical engineering from Purdue University. Her father, Jerry Ross, was born in Crown Point, Indiana, graduated from Purdue University, and is a retired astronaut. Her mother, Karen Ross, was born in Sheridan, Indiana, and is a food technologist working with United Space Alliance, preparing food for astronauts.

Procedures

- Remind students that in previous lessons, they have learned about living and working on board the International Space Station.
- Ask students to suggest reasons why it might be necessary for astronauts to work outside the space station. What do they think the environment outside would be like? What would astronauts need to survive?
- Discuss students' suggestions and explain that sometimes astronauts must work outside the spacecraft in what is called **Extravehicular Activity (EVA)**, and need specialized equipment to protect them from the unforgiving space environment.
- Show students photos of EVA spacesuits and explain that engineers have designed them as a "life raft" that protects the astronaut from extreme temperatures and lack of atmosphere.
- Have students examine the photos to identify and list the safety features and work accessories. In addition to the spacesuit, astronauts have a **tether,** a cord or belted attachment that was originally designed to provide oxygen to the astronaut while performing an EVA. The secondary use was to keep the astronaut secured to the spacecraft. Design has been improved over time so the tether is less clumsy and now used for safety.
- Ask students: What do you notice about the suit and accessories? What are some challenges astronauts might have while working in a spacesuit? Students will probably notice that the suits are bulky and that tools and accessories are attached to a tether to keep them from floating way if dropped.
- Give several students an opportunity to try to connect a bolt, nut, and washer while wearing work gloves. Ask if this seems like an easy task.

Above: Astronaut Piers J. Sellers, STS-121 mission specialist, participates in the mission's third and final session of extravehicular activity (EVA). The demonstration of orbiter heat shield repair techniques was the objective of the 7-hour, 11-minute excursion outside Space Shuttle Discovery and the International Space Station. PHOTO CREDIT: NASA

- Point out that doing simple tasks like this on Earth is actually much easier than when working in space because of the necessity of wearing a spacesuit and space gloves. Practice on Earth is important to prepare for work during an EVA.
- Tell students they will have the opportunity to try a **simulation** of an EVA, just as astronauts do. Some astronauts carry out simulation tasks for two years on Earth before attempting them in space.
- Divide the crew into four teams. Explain to the teams that this is a simulation where they must complete an EVA task in a limited amount of time. Explain that astronauts have time limits, too, because of the dangers of remaining outside the spacecraft too long.
- Provide each team with this scenario:

Your EVA Mission

You are a crew of astronauts aboard the ISS. A large electrical circuit panel needs repair. You must go outside the ISS and perform an EVA to make the repair. First, you will be tethered to your wrench and tethered to your spacecraft (desk or heavy furniture). You will need to manipulate nuts and bolts in a small supply box while wearing your spacesuit gloves. You will have two timed attempts to complete this mission. Your teammates will record your time and notes in their crew logbooks. Compare the two attempts.

- After the entire crew has had a chance to experience an EVA, use the crew logbook notes to discuss the task and results. Did the astronaut improve with the second attempt?
- Ask students to address these questions in their logbooks: How do Earth simulations help astronauts work in space? What inventions could make EVAs easier for astronauts to accomplish in space?

Teacher Tip

It is best to arrange classroom furniture prior to this lesson for safe workspace. Try this experience using a closed supply box so the astronaut who is carrying out the work cannot see the nuts and bolts. This is often the case in an actual EVA because the spacesuit makes it difficult to see. A teammate explains the order of steps to accomplish the task.

Above: In 1965, astronaut Edward White made the first U.S. spacewalk, tethered to his Gemini 4 capsule. White is pictured above holding a compressed gas "zip gun" for maneuvers in his right hand. His spacewalk began over the Pacific Ocean near Hawaii and ended 23 minutes later above the Gulf of Mexico. PHOTO CREDIT: NASA

STUDENT HANDOUT

SUITING UP FOR SPACE

Above: A prototype of NASA's Z-2 spacesuit is pictured at the Johnson Space Center. Planned for use by astronauts as they travel to new deep-space locations, the suit incorporates a number of technology advances to shorten preparation time, improve safety, and boost astronaut capabilities during spacewalks and surface activities. (Oct. 14, 2015) PHOTO CREDIT: NASA

Experience 3: Rise to the Challenge

In this culminating experience, students choose an engineering challenge that applies to living and working in space. They work in teams to brainstorm, design, and build a 3D model of an everyday tool, a utensil, a piece of equipment, or even a new module for the International Space Station. Teams will create an engineering sketch to redesign an everyday tool, utensil, or object for use in space, and then present their ideas to their peers.

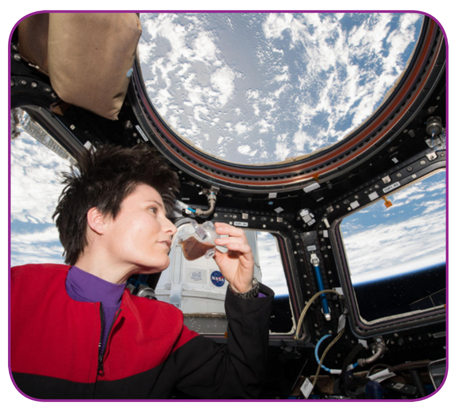
Above: The Mulitpurpose Precision Maintenance Tool, created by University of Alabama in Huntsville student Robert Hillan, was printed on the International Space Station. It is designed to provide astronauts with a single tool that can help with a variety of tasks, including tightening nuts or bolts of different sizes and stripping wires. PHOTO CREDIT: NASA

Procedures

- Remind students that they have learned about orbit, microgravity, energy, space food, life support, lab experiments, and the tools astronauts use on board the ISS. They have also experienced a simulated EVA and now have a better understanding of some of the needs, complexities, and hazards of living in space. Now it's time to put their knowledge to work!
- Tell students they are going to simulate being part of an aerospace engineering team to brainstorm and design a new tool, a utensil, a piece of equipment or even a new module for the ISS.
- Conduct a preliminary session with the entire class to define the task. Ask: What is a space problem that needs to be resolved? What tools, equipment, or personal objects could we invent or improve upon to solve this problem? Would making changes or adding to the ISS solve the problem? Could we add a new module? What would be its purpose? What would it look like?
- Encourage students to use their imaginations as they brainstorm and remember that some ideas that may seem crazy at first turn into real inventions.
- Have student volunteers take notes on sheets of poster paper. As problems and ideas for solutions emerge, help students group them into general categories, such as personal items, tools, utensils, equipment, and modules.

Above: Six space cups as delivered to NASA January 2015 for the Capillary Effects of Drinking in the Microgravity Environment investigation. PHOTO CREDIT: NASA/ANDREW WOLLMAN

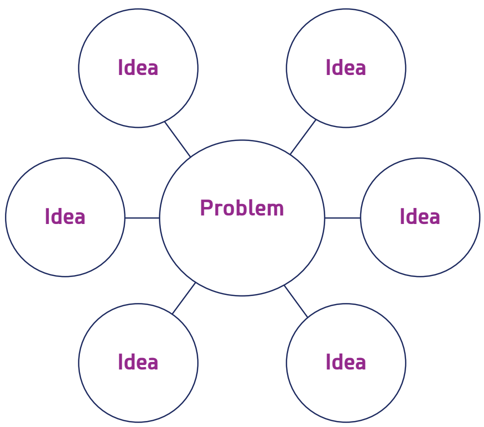
Below: ESA astronaut Samantha Cristoforetti takes a sip of espresso from a space cup during the Capillary Beverage investigation. PHOTO CREDIT: NASA



- Place students in teams based on their interests and begin their work using the following engineering design steps:

  Define: In teams, draw an Idea Web on poster paper to identify the problem they want to solve in the center.

  Brainstorm: Think of ideas for tools, equipment, objects, or modules that would address the problem. Refer to crew logbook notes, questions, and data.



Evaluate: Analyze the ideas and consider what is really possible. Select one idea that will be the team's focus.

Design: Make and refine sketches of the module or tool idea in the crew logbooks.

Make a list of the materials needed to build a new module or space tool/object.

Build: Build a **prototype**, or 3D model, using modeling clay or other materials.

Test: Test the design in gravity but consider how it would be used in microgravity. Will it work? Does the idea need to be redesigned?

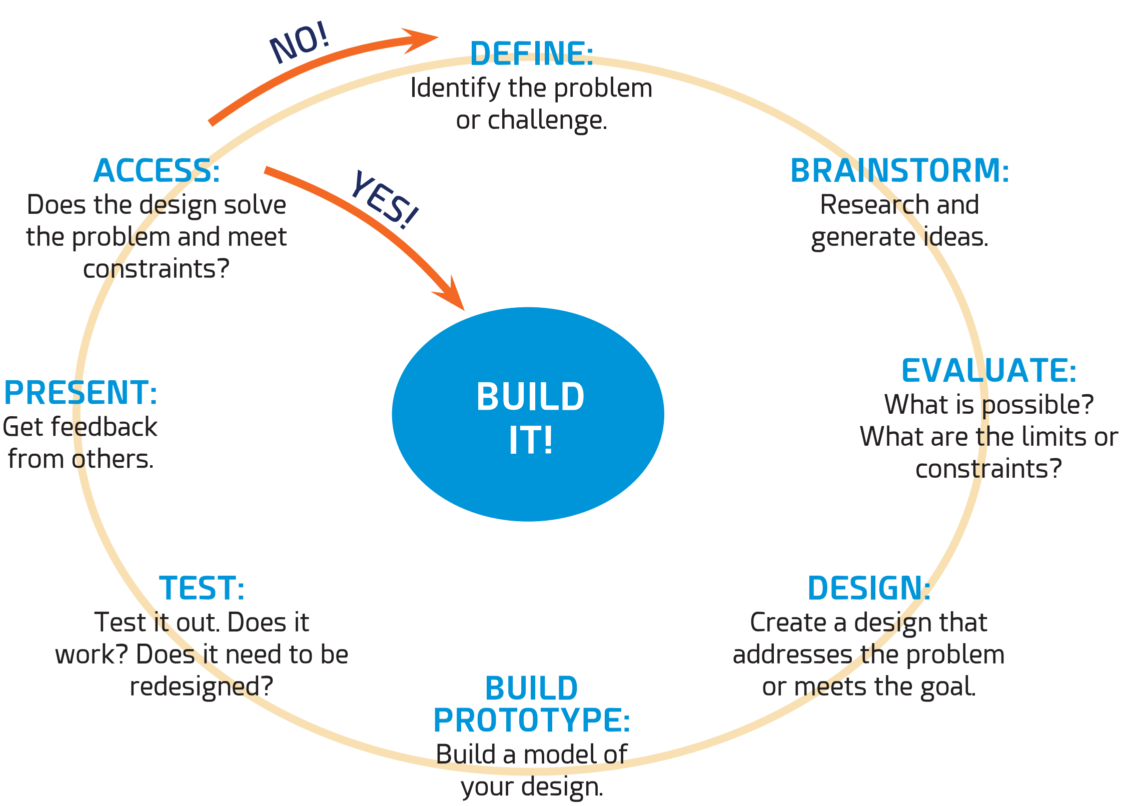
Present: Present the final design to the entire crew and possible guests, such as parents, staff, and community members, including engineers or scientists. Allow for feedback.

Assess: Use feedback from the crew and guests to assess the final design.

- Did the new design take into consideration that it would be used in microgravity?
- How was it modified for microgravity?
- Will it make life on board the ISS better/easier/enhanced/improved/more comfortable?
- Is it useful?
- Is it practical?
- Is the design adaptable for use on Earth?
- Are more changes needed?

Teacher Tip
For more information on the engineering design process, visit: http://www.pbslearningmedia.org/resource/phy03.sci.engin.design.desprocess/

ENGINEERING DESIGN PROCESS



Assessment: Designing Science on the ISS

Have students use prior unit experiences to create their own research proposal for an ISS experiment. Scientists, engineers, and space enthusiasts around the world have presented their ideas for space research to NASA.

Above: Testing of the *Made In Space* 3D printer involved 400-plus parabolas of microgravity test flights. PHOTO CREDIT: NASA

Ask students to think about ideas, materials, tools, or equipment that could be tested in a microgravity environment. For example, they might identify a substance on Earth, consider how it acts in full gravity, and propose to test how it would behave in microgravity. They might identify a problem related to living in space that needs to be solved and propose to test the tools or equipment that might be the solution. Students should develop a research proposal for testing items or processes on board the International Space Station in a microgravity investigation.

Students can use crew logbooks to prepare their proposals using the following format:

Title

Student name

Description of Proposal

Question(s) to be addressed by the experiment

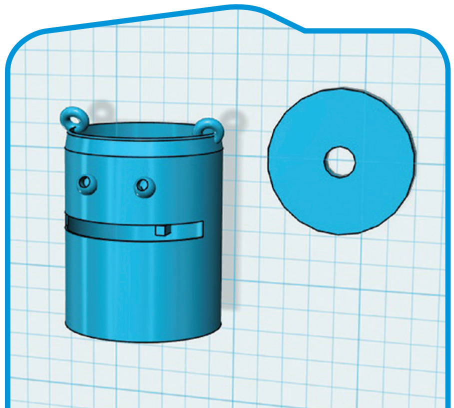
Justification for this experiment

Materials, supplies, experiment requirements

Experiment plans (include designs, sketches, charts, etc.)

Bibliography of resources

Evaluate students on the basis of their thoroughness in identifying a problem or defining an idea to be tested, the clearness of their proposal, and their ability to support the proposal with justifications, experiment requirements, visuals, and research. After teacher and peer review, feedback, and revision, encourage students to submit their proposal to NASA or Student Spaceflight Experiments Program (SSEP) for study. Some students as young as Grade 5 have been selected to fly an experiment on board the shuttle or space station.



Above: Space Planter designed by Sydney Vernon from Bellevue, Washington. Sydney is the winner of the Junior Group (ages 5–12) of the Future Engineers 3D Printing in Space Tool Challenge. IMAGE CREDIT: SYDNEY VERNON

Below: Sydney during her finalist interview with Astronaut Reid Wiseman.

PHOTO CREDIT: NASA, ADRIENNE GIFFORD

GLOSSARY

acceleration: A continuous change in orbital direction and speed of one body around another.

angle: The aim of a launched projectile, such as a rocket or spacecraft, that predicts its trajectory and landing point.

biodome: A type of closed ecological system that is self-sufficient and closely replicates nature.

closed system: A closed ecological system that does not rely on matter exchange with any source outside the system. Any waste products from one species must be used by at least one other species.

conductor: An object, substance, or material that allows the flow of an electric charge.

crystalline substance: A solid material in which the atoms, molecules, or ions form a regular pattern in three dimensions.

current: The flow of an electric charge carried by electrons moving in a wire.

dehydration: A chemical reaction that results in the loss of water molecules.

electrical circuit: A complete path through which an electric current can flow.

electricity: A set of physical phenomena associated with a current in which electric charges produce electromagnetic fields that act on other electric charges.

electromagnetic waves: Synchronized movements of electric and magnetic fields that multiply at the speed of light through a vacuum.

energy: The potential of a substance to be transformed by a chemical reaction to other substances. The kinetic energy an object possesses is due to its motion during acceleration. The thermal energy of an object is due to its internal temperature.

EVA (Extravehicular Activity): Any activity performed by an astronaut outside a spacecraft beyond Earth's atmosphere.

fluids: Liquids that form a free surface not defined by their containers.

force: Any interaction that when unopposed will change the motion of an object. A force can cause an object to accelerate.

free fall: Any motion of a body where gravity is the only force acting upon it. A body in free fall is said to experience zero gravity, or weightlessness.

friction: The force resisting the motion of solid surfaces, fluid layers, or materials sliding against each other. Friction converts kinetic energy into thermal energy.

gravity: The force that attracts a body toward the center of Earth, or toward any other physical body having mass.

hydration: A chemical reaction that combines a compound with water.

inertia: The continuation of an object's state of rest or uniform motion in a straight line unless that state is changed by an external force.

International Space Station: A large spacecraft and science lab that orbits the Earth and provides a home for astronauts to live and work.

irradiated: Exposed to radiation other than light, such as X-rays.

liquid: A substance that flows freely, like water, but maintains a constant volume.

logbook: A written record of research, activities, events, or travel, similar to a diary.

mass: The quantity of inertia of an object that measures its resistance to acceleration. The mass of an object is roughly the number of atoms in it.

microgravity: The extremely low-gravity condition in which people or objects appear to be weightless, such as when astronauts float in space.

mission patches: Cloth reproductions, typically embroidered, of a spaceflight mission emblem worn by astronauts and other mission personnel.

modules: The parts of a spacecraft.

orbit: The curved path of a celestial object or a spacecraft around a star, planet, or moon, especially a periodic elliptical revolution.

Personal Preference Kit (PPK): A container, approximately 12.82 cm by 20.51 cm by 5.13 cm (5" by 8" by 2") in size, separately assigned to each individual accompanying a space shuttle flight for carrying personal mementos during the flight.

prototype: A preliminary model of something used to test the design.

radiant energy: Energy that travels by waves or particles, such as heat or X-rays.

rehydration: A chemical reaction that causes a dehydrated object to reabsorb moisture.

simulation: An imitation of the operation of a real-world process or system, often using a prototype.

solar: Radiant energy from the sun's rays.

solution: A mixture of two or more similar substances; the condition of being dissolved, such as borax when stirred into water.

surface tension: The tension of the surface film of a liquid caused by the attraction of the particles in the surface layer by the bulk of the liquid.

tether: A long safety cable that allows astronauts to work outside a spacecraft without floating away into space. Astronauts also use tethers to keep their tools from floating away.

thermostablized: Preserved by heat, usually under pressure, to destroy microorganisms such as bacteria and viruses.

thrust: The propulsion force of an object, such as a spacecraft.

volume: The amount of space that a substance or object occupies.

weight: A substance's or an object's relative mass or the quantity of matter contained by it, causing a downward force.

BOOKS AND WEBSITES

NONFICTION BOOKS

Becker, Helaine, and Brendan Mullan. *Everything Space.* Washington, D.C.: National Geographic Kids, 2015.
This fun book launches readers from the space they're familiar with on Earth into outer space and among its planets, stars, and more. More than 250 fascinating facts about space and space explorers are illustrated with photos and infographics. Suitable for Grades 3 through 7.

Bennett, Jeffrey O., and Michael W. Carroll. *Max Goes to the Space Station: A Science Adventure with Max the Dog.* Boulder, CO: Big Kid Science, 2014.
Follow Max on his trip to the International Space Station and share his adventures of astronaut life! This picture book introduces students in Grades 3 through 5 to a global perspective of Earth and encourages them to think of innovative ways to make the world a better place. "Big Kid Box" sidebars throughout the book highlight science facts.

Berne, Emma Carlson. *Totally Wacky Facts about Exploring Space.* North Mankato, MN: Capstone, 2015.
How much does a spacesuit weigh? Which astronaut played golf on the moon? Where do astronauts put their dirty underwear? A colorful, contemporary design pulls even the most reluctant readers into this book to learn surprising facts about life in space. Suitable for Grades 3 through 8.

Blobaum, Cindy, and Bryan Stone. *Explore Gravity!* White River Junction, VT: Nomad, 2013.
Students in Grades 3 through 5 will enjoy the 25 easy projects included here that reinforce gravity vocabulary words and provide hands-on STEM activities that use everyday objects to build a deeper understanding of weight, matter, attraction, and gravitational pull.

Brake, Mark. *How to Be a Space Explorer: Your Out-of-This-World Adventure.* Oakland, CA: Lonely Planet, 2014.
For the aspiring astronauts in your classroom, this book presents everything they need to know about travel in space: how to navigate the solar system, how to live in microgravity, and how to go to the bathroom while wearing a spacesuit! The astonishing true stories and hundreds of amazing photos are recommended for Grades 3 through 8.

Branley, Franklyn M., and Kevin O'Malley. *The Planets in Our Solar System.* New York: Harper, 2015.
This classic picture book has been examined for accuracy by NASA and updated to reflect changes in current understanding of the planets. It also includes a solar system mobile-making activity and web-research prompts about how to track the moon. Aligned with science standards, this national prize–winning title is useful for introducing students in Grades 3 through 5 to more challenging concepts in space exploration.

Buckley, James. *Home Address: ISS: International Space Station.* New York: Penguin Young Readers, 2015.
How do you manage day-to-day life when your new home is far away from Earth and you're living in microgravity? This title is a good basic introduction to life aboard the ISS, and the photos help students in Grades 3 through 5 understand the challenges of teamwork in outer space.

Buckley, James. *Space Heroes: Amazing Astronauts.* New York: DK, 2004.
For students in Grades 3 through 5, this book presents the history of space exploration and the brave astronauts from the United States and Russia who made the first spaceflights.

Goodman, Susan E., and Michael Slack. *How Do You Burp in Space? and Other Tips Every Space Tourist Needs to Know.* New York: Bloomsbury, 2013.
Students in classrooms now may someday be among the first to vacation in outer space. Introduce them to the many steps required for space travel, including what to pack, how to eat and stay clean, where to sleep, and what to watch for. The text and illustrations, suitable for Grades 3 through 8, are often funny but always realistic.

Hadfield, Chris. *You Are Here: Around the World in 92 Minutes.* New York: Little Brown, 2014. The author, a former commander of the International Space Station, has assembled 192 of his most surprising and enjoyable photos into a story representing one day aboard the station. The accompanying short captions comment on life in zero gravity and other thought-provoking topics. This is not a juvenile book but older students can read it on their own and younger students will enjoy the photos as you read aloud.

Hayden, Kate, and Peter Dennis. *Astronaut: Living in Space.* New York: DK, 2012.
Try this reader with younger students who are still learning to read alone. It's a solid introduction to space travel and working in space, and it's told from a female astronaut's point of view. Photos and information boxes throughout introduce new vocabulary.

Morgan, Ben, ed. *Space! The Universe as You've Never Seen It Before.* New York: DK, 2015.
Include this encyclopedia-style reference book on your classroom shelf for students in Grades 5 through 8. It covers everything from stars and planets to night sky and galaxies to space exploration and equipment, and is jam-packed with NASA photos, infographics, computer-generated graphics, and more.

BOOKS AND WEBSITES

Ross, Jerry Lynn, and Susan G. Gunderson. *Becoming a Spacewalker: My Journey to the Stars.* West Lafayette, IN: Purdue University Press, 2014.
This picture book is a children's version of NASA astronaut Jerry Ross's autobiography, especially useful for Grades 3 through 5. Describing how he grew up in rural Indiana, went to Purdue University, and then traveled to outer space, the author emphasizes the importance of curiosity, persistence, and self-assurance. Photos and personal memorabilia engage young readers, while online guides link teachers to additional resources for using the book in the classroom.

Wilkinson, Philip. *Spacebusters: The Race to the Moon.* New York: DK, 2012.
For students in Grades 3 through 5 who are learning to read alone, this is a highly engaging story of the United States' race to be the first to send a man to the moon in the 1960s. As with all DK Readers, this book is heavily illustrated and also includes new vocabulary and complex sentences to build literacy skills.

WEBSITES

CASIS: The mission of the Center for the Advancement of Science in Space is to maximize use of ISS data and images for scientific and commercial innovation that can benefit all humans. From the CASIS website, you can link to articles and videos specifically created for classroom use. http://spacestationexplorers.org/.

Explore Deep Space for Kids. This webpage from the Coalition for Deep Space Exploration website offers a variety of videos, activities, quizzes, images, and links for students in Grades 3 through 8. http://exploredeepspace.com/for-kids/

International Space Station: NASA's official website for the ISS offers images, videos, and articles on crews and expeditions, launches and landings, research and technology, and more. Click on Space to Ground to see the most recent updates. https://www.nasa.gov/mission_pages/station/main/index.html

ISS Tracker: Follow the path and speed of the ISS as it orbits Earth. Tools display longitude and latitude, miles per hour, and altitude. http://www.isstracker.com/

Kennedy Space Center: The Kennedy Space Center maintains a Frequently Asked Questions page all about NASA astronauts—where to write to them, how to get signed photos of them, and answers to a variety of common queries about working in space. https://www.nasa.gov/centers/kennedy/about/information/astronaut_faq.html

NASA Astronaut Biographies: Find out all about your favorite current and former astronauts on this comprehensive site. Each biography is an Adobe Acrobat (.pdf) file that includes education, research, and work background. http://www.jsc.nasa.gov/Bios/astrobio.html

NASA Johnson Flickr: NASA Johnson Space Center maintains photo albums of astronauts at work in space and on Earth. https://www.flickr.com/photos/nasa2explore/albums. Some astronauts have their own individual sites, too, on Facebook, Twitter, and Instagram.

Radiolab "Dark Side of the Earth": In this short podcast, Dr. David Wolf describes the exciting experience of floating outside the Mir Space Station on his very first spacewalk. Click on Stream to hear his amazing stories. http://www.radiolab.org/story/242184-dark-side-earth/

Spot the Station: The International Space Station looks like a fast-moving plane high in the sky. It's easy to spot if you know when and where to look for it. Find out how on this site! You can also embed the tool on your class or school website. https://spotthestation.nasa.gov/

STEM on Station: NASA's ISS website for educators includes STEM activities related to the space station; current info on research and crew; and lesson plans, videos, and up-to-the-minute news you can use in the classroom. https://www.nasa.gov/audience/foreducators/stem_on_station/index.html

Windows on Earth: NASA astronauts send amazing photos of Earth and its atmosphere from their voyages! See them here, categorized by subject matter and most recent images. http://www.windowsonearth.org/

Indiana Science Standards (2016)

K–12 Science and Engineering Process Standards

SEPS.1 Posing questions (for science) and defining problems (for engineering)

SEPS.2 Developing and using models and tools

SEPS.3 Constructing and performing investigations

SEPS.4 Analyzing and interpreting data

SEPS.5 Using mathematics and computational thinking

SEPS.6 Constructing explanations (for science) and designing solutions (for engineering)

SEPS.8 Obtaining, evaluating, and communicating information

Physical Science

4.PS.1 Investigate transportation systems and devices that operate on or in land, water, air and space and recognize the forces (lift, drag, friction, thrust and gravity) that affect their motion.

4.PS.2 Investigate the relationship of the speed of an object to the energy of that object.

4.PS.4 Describe and investigate the different ways in which energy can be generated and/or converted from one form of energy to another form of energy.

4.PS.5 Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.

5.PS.1 Describe and measure the volume and mass of a sample of a given material.

5.PS.3 Determine if matter has been added or lost by comparing mass when melting, freezing, or dissolving a sample of a substance. (Law of Conservation of Mass)

5.PS.4 Describe the difference between weight being dependent on gravity and mass comprised of the amount of matter in a given substance or material.

6.PS.2 Describe the motion of an object graphically showing the relationship between time and position.

6.PS.4 Investigate the properties of light, sound, and other energy waves and how they are reflected, absorbed, and transmitted through materials and space.

7.PS.4 Investigate Newton's first law of motion (Law of Inertia) and how different forces (gravity, friction, push and pull) affect the velocity of an object.

7.PS.5 Investigate Newton's second law of motion to show the relationship among force, mass and acceleration.

7.PS.6 Investigate Newton's third law of motion to show the relationship between action and reaction forces.

Earth and Space Science

6.ESS.1 Describe the role of gravity and inertia in maintaining the regular and predictable motion of celestial bodies.

Life Science

6.LS.1 Investigate and describe how homeostasis is maintained as living things seek out their basic needs of food, water, shelter, space, and air.

Engineering

3-5.E.2 Construct and compare multiple plausible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

3-5.E.3 Construct and perform fair investigations in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

6-8.E.1 Identify the criteria and constraints of a design to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

6-8.E.2 Evaluate competing design solutions using a systematic process to identify how well they meet the criteria and constraints of the problem.

6-8.E.3 Analyze data from investigations to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

6-8.E.4 Develop a prototype to generate data for repeated investigations and modify a proposed object, tool, or process such that an optimal design can be achieved.

National Standards

Next Generation Science Standards

Physical Science

5-PS1-2 Measure and graph quantities to provide evidence that regardless of the type of change that occurs when heating, cooling, or mixing substances, the total weight of the matter is conserved.

5-PS1-3 Make observations and measurements to identify materials based on their properties.

MS-PS1-1 Develop models to describe the atomic composition of simple molecules and extended structures.

MS-PS1-2 Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

MS-PS1-4 Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.

MS-PS1-5 Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved.

5-PS2-1 Support an argument that the gravitational force exerted by Earth on objects is directed down.

4-PS3-2 Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.

4-PS3-4 Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

MS-PS3-3 Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.

Life Science

4-LS-1 Construct an argument that plants and animals have internal and external structures that function to support survival, growth, behavior, and reproduction.

5-LS-1 Support an argument that plants get the materials they need for growth chiefly from air and water.

MS-LS2-4 Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

Engineering Design

3-5-ETS1-1 Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

3-5-ETS1-2 Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

3-5-ETS1-3 Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

MS-ETS1-1 Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-3 Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-ETS1-4 Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.