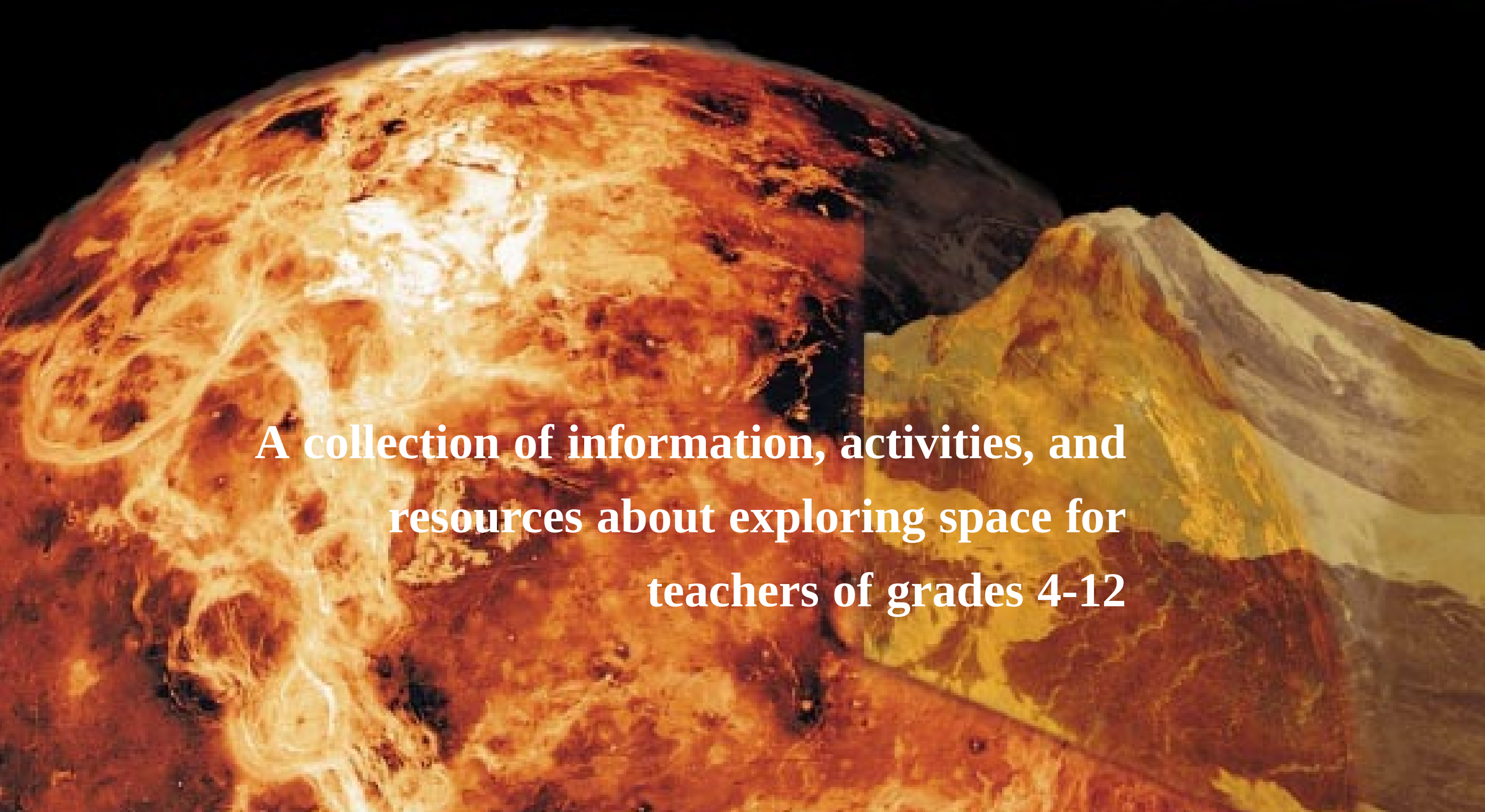
Educational Services Department
National Air and Space Museum
Smithsonian Institution

DESTINY IN SPACE



A collection of information, activities, and resources about exploring space for teachers of grades 4-12

Contents

Acknowledgments 1
Subject and Grade Level 2
How to Use This Book 3
Introduction 4

Sociological and Biological Challenges

Why Go? Motives for Exploring Space 8
Wearing Weight: How Muscles Respond in Space 12
Ears, Eyes, and Toes: How You Keep Your Balance 15
Faraway Feelings: Isolation and Separation 21

Technological Challenges

Telescopic Eyes: What Makes Good Viewing? 24
Robotic Guides: Preparing for Human Exploration 28
Phoning Home: Communicating Across Space 35
Sending Signals: Programming Robots 39
Spinning Spacecraft: Simulating Gravity 42
Suiting Up for Space: What to Wear Out There 47
You Can Take It With You: In Fact, You Have To 53
Gardening in Space: Sustaining Humans 57

Resources 62
Where can you see *Destiny in Space?* 64

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Ideas and Illustrations
[50] The author first saw the activity in the *Try This* section at the NASA Kennedy Space Center's activity room.
[39] *Sending Signals* is based on an activity developed by NASA Aerospace Education Specialist, Will Robertson (Marshall Space Flight Center).
[10,11] Icon images developed for *Why Explore?* computer interactive exhibit on display in gallery 209, *Where Next, Columbus?*
Producer Jack Sculley, Illustrator Mike Buettner.

Subject and Grade Level

	Biology	Earth Science/Geology	Environmental Science	Government/Law/Econ.	Meteorology/Weather	Physical Education/Health	Physical Science/Physics	Psychology/Sociology	Speech/Debate	Technology	Grades 4 – 5	Grades 6 – 8	Grades 9 – 10	Grades 11 – 12
Ears, Eyes, and Toes	●						●					●		
Faraway Feelings								●					●	
Gardening in Space	●									●			●	
Phoning Home							●	●		●		●		
Robotic Guides		●			●		●		●				●	
Sending Signals										●	●			
Spinning Spacecraft							●			●				●
Suiting Up for Space			●							●		●		
Telescopic Eyes			●		●		●			●		●		
Wearing Weight	●					●					●			
Why Go?				●					●					●
You Can Take It With You			●			●				●	●			

How to Use This Book

These activities are intended to be used as supplements to your curricula. Each activity addresses a major challenge of exploring space; the collection of activities, however, should not be considered a comprehensive or definitive work on the subject. Although these activities work well on their own, we hope you will be able to view *Destiny in Space* (the National Air and Space Museum's newest IMAX film) in conjunction with this curriculum. (See the inside back cover for a listing of IMAX/OMNIMAX theater locations.)

We have designed the activities to work with a variety of teaching styles and student abilities. For example, you can simplify an activity by omitting data collection and the section titled Problems. In each activity, the questions generally proceed from concrete to abstract and from simple to challenging. The matrix on page 2 recommends appropriate grade levels and subjects for each activity.

We have cited measurements according to the standards of the Smithsonian Institution. Most weights and measures are cited in metric units followed, in parentheses, by the English equivalents. In a few cases the mathematical calculations involved when using English units are so complicated that only metrics are used. Volumes are cited in U.S. measurements, rather than Imperial measurements.

In each activity, we stress the importance of making and recording careful observations—but we have included few worksheets. Instead, we suggest that students keep their information in a journal. Less structured than worksheets, journals provide a place for students to record interpretations, illustrations, and raw data in much the same way as actual researchers.

Introduction

For most of human history, knowledge of space has been confined to information about the heavens which we and our instruments could detect from here on Earth. Initially we relied on our limited eyesight to interpret the cosmos, then telescopes enhanced our view of the stars. Only in the last four decades have we been able to leave Earth and experience space firsthand.

The universe is immense. After decades of breakthroughs, we still have no hope in the near future of overcoming certain restrictions on the type and range of exploration. For example, Mars is a reasonable destination for astronauts, but Pluto is not. And while Pluto is within reach of robotic spacecraft, the nearest star beyond the Sun (Proxima Centauri) is not. Today's fastest robotic spacecraft would take tens of thousands of years to reach this star, which is more than 280,000 times farther from Earth than the Sun. We can only explore such destinations by using telescopes.

NASA 92-HC-645

Curtis Brown and Japan's Mamoru Mohri prepare to use chopsticks in space. Mission planners strive to provide food that astronauts enjoy. Their task becomes increasingly challenging as international crews become more common.

In addition to physical constraints, space exploration is also limited by available resources. Work proceeds in bursts reflecting the economy and politics of the time, and competing goals further affect the choices of destination and methods of exploration. (See the activity, "Why Go?")

A positive outcome of these resource restrictions is their role in fostering international cooperation in space exploration. Until the 1970s, individual nations generally conducted space research independently. With changing political climates and the increasing expense and challenge of space exploration, international cooperation is becoming the norm. For example, astronomers around the world use information from orbiting space telescopes, and multinational crews are working together on both Russian and American missions.

Whether they are independent or multinational efforts, projects that are undertaken connect the past, present, and future by building on previous exploration and preparing for future trips. Some of the people who began their careers working on the *Voyager* probes have seen their children become scientists and interpret data from those same probes. When the *Hubble Space Telescope* was sent into orbit aboard the Space Shuttle in 1990, three generations watched the launch—Dr. Lyman Spitzer who suggested a space telescope in 1946, the scientists who designed *Hubble's* special instruments, and children who will be learning about the universe from data collected by *Hubble*.

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Before venturing into space to repair the *Hubble Space Telescope*, astronauts practice using specialized tools in a laboratory.

Sending Astronauts

When Neil Armstrong stepped out of the Apollo 11 lunar lander in 1969, he was fulfilling a dream that visionaries have shared for centuries: Humans had arrived on the Moon. But this incredible accomplishment was not without significant cost, including the lives of three Apollo astronauts who died when fire swept through their command module during a ground test.

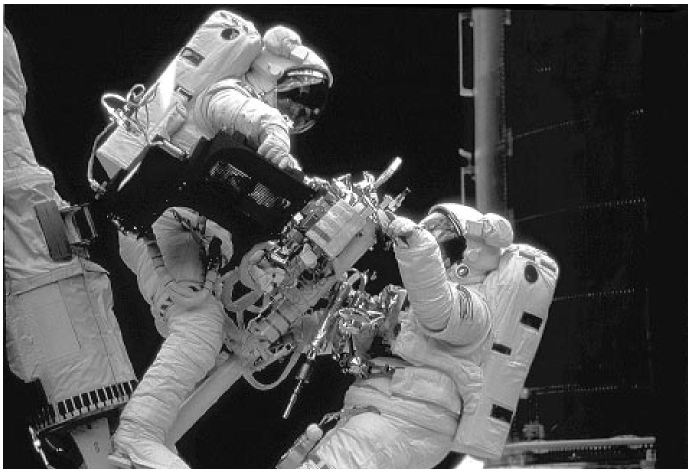
Sending humans into space is risky and expensive. Astronauts require life-support equipment that adds cost, space, and weight to a spacecraft. Astronauts also look forward to coming home, so "round-trip tickets" are essential additions to the expense and duration of the trip. And the longer the trip, the longer the astronauts are exposed to the hazards of space flight such as equipment failure, weightlessness, and cosmic radiation. (See the activities, "Wearing Weight," "Ears, Eyes, and Toes," and "Spinning Spacecraft.")

If sending people into space is so risky and expensive, why do we do it? Proponents of astronautics argue that only human emissaries can so fully capture our imagination. More important, the space environment allows us to establish a unique research laboratory that would require skills far beyond those of even the most adept robots. Sending people into space is also the only way to learn about the physiological and psychological effects of long-duration space flight on humans.

While opponents of astronautics argue for exclusive robotic exploration, most people in the field realize that both people and robots play essential roles in exploring space. People are needed to design the intricate, precise mechanical instruments that extend our reach and expand our view; people are needed to operate the instruments from Earth; and people are needed to maintain some of these machines. For example, astronauts repaired the *Hubble Space Telescope* while in Earth orbit.

Actions we perform easily on Earth are often much more cumbersome in space. To train for space missions, astronauts practice under water where the weightlessness of space can be partially simulated. They also learn to manipulate tools while wearing bulky suits and gloves. They may even simulate handling the Shuttle's robotic arm by using a device that allows them to see and feel the tool as if they were in the Space Shuttle. In the future, such training may take place in the real environment of space aboard a permanently orbiting space station.

Some proponents of a space station also perceive it as an excellent training platform for future trips to Mars. But before humans can travel to Mars, we must learn more about how and why our bodies react to long-term space travel. We must also provide enough resources for astronauts during the year-long flight. (See the activities, "You Can Take It With You" and "Gardening in Space.") We must also recognize that astronauts are not always the best explorers of space.



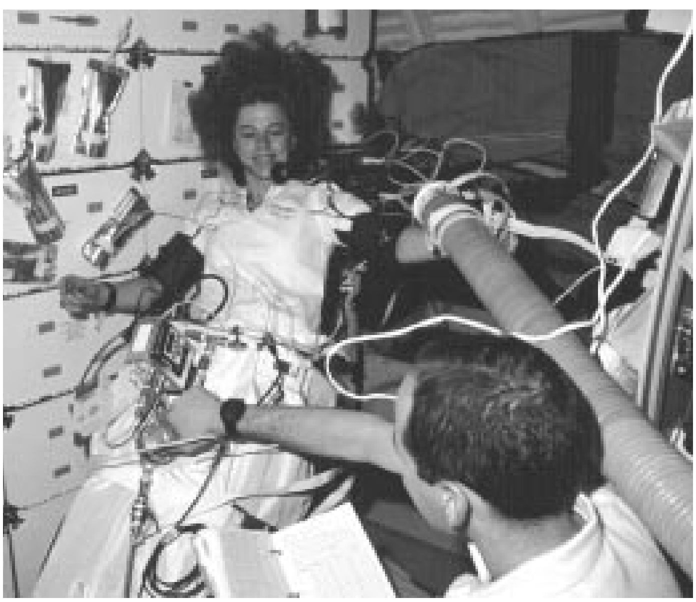
Astronauts prepare to work on the *Hubble Space Telescope*. First they must find the correct tool among an array of specially designed equipment.

Sending Robots

While highly memorable, the Apollo 11 landing did not bring the first emissaries from Earth. Space exploration by astronauts occurs only after a long series of missions by robotic spacecraft. Armstrong's historic footsteps were preceded by crewless spacecraft that collected data as they flew by, orbited, and/or landed on the Moon. Such robotic exploration helps mission planners determine if astronautic exploration is advisable.

Chances are good that if students describe a robot, they will picture a shiny metal android (humanlike machine) that performs tedious tasks without complaint. While such machines do exist, most of today's real robots bear no resemblance to humans. For example, a robot that strips paint off airplanes looks more like a construction crane than a human. Some people even consider answering machines to be a kind of simple robot because they can be remotely programmed.

Robots can perform long-term passive tasks such as monitoring seismic activity or repetitive tasks such as building other machines that most humans would find unbearably tedious. They can work in realms that are hazardous or deadly to humans, such as cleaning up toxic spills or measuring radiation leaks inside a nuclear reactor. They can also explore volcanoes, ocean trenches—and our solar system.



NASA 90-HC-49

Shuttle astronauts study how weightlessness affects humans. Here, Bonnie Dunbar is wearing a device that pulls body fluids toward her feet. David Low monitors the test.

Robotic spacecraft have been sent to fly by, orbit, and land on other worlds throughout our solar system. They are used to map Earth and other planets, to see what we can't see, and to analyze what we can't touch. Without robots, our exploration of planets such as Venus and Jupiter would be severely limited because such places are too harsh for humans to visit. Lead would melt on the super-heated surface of Venus and no living thing could survive the intense radiation surrounding Jupiter; yet spacecraft can be designed to withstand these hazards, at least for a short time. *Venera 17* sent data from the surface of Venus for just over two hours before over-heating; *Voyager* withstood Jupiter's radiation as it flew by and sent data back to Earth.

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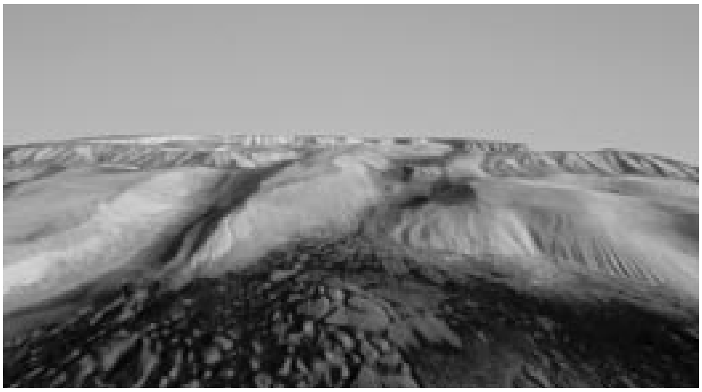
The robotic spacecraft *Galileo* is released into space from the cargo bay of the Space Shuttle *Atlantis* to begin its five-year journey to Jupiter.

In places where humans might some day go, robots also serve as advance scouts. (See the activity, "Robotic Guides.") On Mars, *Viking* spacecraft radioed data that gave us information about what human visitors might find. Although the landers found no organic materials that would indicate life, their orbiting counterparts recorded channels and other geologic features that appear to have been formed by flowing water. Perhaps one day a robot or a paleontologist will uncover fossils in those channels.

Robots are efficient space explorers because they don't need to return to Earth, and they don't require expensive life support systems. They do, however, present significant challenges. They must be intricately programmed to perform tasks such as turning or walking, which many of us take for granted. (See the activity, "Sending Signals.") If robots are controlled from a remote site, operators must also deal with signal delays that are inherent when communicating across space. For example, a rover teetering on the edge of a canyon on Mars would have to wait at least four minutes for instructions to be sent from Earth. (The activity, "Phoning Home" explains these delays.)

Communication problems notwithstanding, robotic devices are still powerful tools, and as computing capabilities advance, robot independence and ability increase. Today's robots can scan and map their immediate environment while onboard computers direct their course across a boulder field or crevasse without further instruction from a human operator.



NASA JPL

This three-dimensional view of Candor Chasma on Mars was constructed from data collected by the robotic spacecraft, *Viking*, and was sent to Earth in much the same way as a television signal.

Technology will continue to expand the abilities and range of robots, but robotic space exploration will always have limits. Stars and planets outside our solar system are so far away that neither humans nor spacecraft could reach them within a thousand lifetimes. How can we explore these remote places in space?

Eyes On the Sky

While it is unlikely that we will be able to travel to stars in the foreseeable future, stars send information to Earth by means of the fastest known traveler—light. Most of what we know about the universe is the result of collecting and analyzing light from distant objects. From the time of Galileo, telescopes have helped us see far beyond Earth. Cosmic bodies naturally give off many kinds of light including gamma rays, x-rays, ultraviolet, visible, infrared, and radio waves. Telescopes can be designed to collect these various types of light, which we study to learn about our universe.

Only a few of the various types of light—visible light, infrared, and radio waves—penetrate Earth's atmosphere to any appreciable degree. The planet's atmosphere and commercial radio signals disturb incoming signals from space. To avoid this disturbance, huge optical telescopes are placed where the sky is clear and calm, infrared telescopes are placed where the air is very dry, and radio telescopes are located away from busy cities. Telescopes that detect short wavelength radiation, such as x-rays and gamma-rays, must be located above our atmosphere, which substantially absorbs such signals. (See the activity, "Telescopic Eyes.")

Above the atmosphere, Earth orbit serves as the ultimate mountain top. Telescopes placed in orbit can collect any type of light from space without atmospheric disturbance. Each different kind of light presents a unique view of the sky. Examining the same region of space with different instruments reveals different objects and physical processes. For example, an object that is invisible to Hubble's optical telescope might show up clearly when examined by the instruments on the orbiting Gamma Ray Observatory.

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Many cosmic bodies emit radio signals naturally. Radio telescopes, like the one shown here, can collect such signals, can be used to communicate with robotic spacecraft, and can listen for signals from other possible civilizations in the galaxy.

Telescopes in space allow scientists to look into the farthest reaches of the universe. In the mid 1970s, *Skylab* (America's first space station) carried eight telescopes into space to view the Sun in visible, ultraviolet, and x-ray light. The *Infrared Astronomical Satellite* (IRAS), deployed in 1983, revealed numerous objects that were previously undiscovered because they do not give off visible light. Now, the *Hubble Space Telescope*, one of the largest astronomical space observatories, orbits more than 480 kilometers (300 miles) above Earth.

Stars and planets are only two of the things that telescopes look for. The Search for Extraterrestrial Intelligence program (SETI) uses Earth-based radio telescopes to listen for artificial radio signals from other parts of our galaxy. If other intelligent beings exist, perhaps they also know how to communicate using radio waves.

As we create more sophisticated telescopes and robotic space explorers, will we still send humans into space? Will we be satisfied to explore through the eyes of the machines we create? The activities in this guide enable you and your students to explore these and other crucial questions and challenges that are described in the IMAX film, *Destiny in Space*, and that will face us all in the future.

Why Go?

Motives for Exploring Space

Goal

To examine various reasons for exploration in an effort to become educated decision makers

Key Concepts

- Exploration is usually a cultural enterprise instead of an individual effort.
- Many of the motives of exploration are still debated.
- Historically, exploration has competed with other activities for approval and resources.

Overview

Explorers rarely explore alone—they are often actors in a drama that represents the choices of their culture. In this panel discussion, students engage in making such choices. They discover that decisions about the merits of space exploration are complicated.

Materials

For presenters:

Student Sheets on pages 10 and 11

For audience:

Counters, 10 per student
Six cups

Preparation

For teacher:

- A week before the final presentation, select six students to present the six viewpoints in this panel discussion, and one student to serve as moderator.
- Label the six cups, each with one of the viewpoints that will be discussed.

For presenters:

Prepare your remarks as completely and concisely as possible based on your research and the *Student Sheets*. You will have four minutes to present your position and two minutes to answer questions from the audience.

Procedure

For moderator:

a. Assign a timekeeper.
b. After the presentations, pass out 10 counters to each audience member.
c. After the audience votes, count the votes and announce the results.

For presenters:

a. Determine order of presentation by drawing pieces of paper numbered 1–6.
b. Take turns presenting your assigned motive for exploring space (or for not exploring). Each presenter has four minutes.
c. In reverse order of the presentations, take two minutes each to respond to questions from the student audience.

For audience:

a. As you listen to each presentation, write down questions you wish to ask the presenter.
b. Cast your vote. Either divide your 10 counters in any combination among the five motives for exploration or cast all 10 counters for the “Stay Home” position.

Questions

1. Which motive received the most votes?
2. Is this outcome what you expected?
3. In your opinion, why did that motive win?
4. How might the results differ if your parents’ generation was voting on the six choices?
5. Did the presentations change your thoughts about what should motivate our exploration of space? If yes, explain why you changed your mind.
6. How should we encourage Congress to spend our money on space exploration?

Why Go?

More Ideas

Before the panel discussion, take a class poll to find out how people feel about space exploration. Repeat the poll after the panel discussion and compare the results. How did the presentations affect opinions?

In the Film

As you watch the film, try to identify some of the motives for exploring space. There are references to curiosity and colonization; can you find others?

Artist's concept of how terraforming could change Candor Chasma, Mars. The theory of terraforming describes how the surface of a planet such as Mars could be changed enough to create conditions for life. Such ideas, considered radical by many, fuel dreams of colonization.

To the Teacher

As students review the six motives for or against exploration, they need to think about which arguments carry the most weight, which might be widely shared, and which are advocated by only a small percentage of individuals. Ask them to anticipate how people might be persuaded to support space exploration and what types of arguments there might be against it. Presenters should be prepared to cite both general and more personal reasons to substantiate their point of view. Ideally, they should be able to research supporting evidence for the arguments and be ready to defend their positions.

The reasons for and against space exploration are meant to serve as outlines only. As students prepare for the presentations, encourage them to think about what motivates people to explore, how this has manifested itself in the exploration of space, how we should explore space, and whether or not we should. Even without extensive student preparation, this activity should stimulate some interesting debate about exploration.

The elaborate voting method used in this activity is an attempt to model real-life decision making as well as to maximize the number of possible scenarios. Students may be surprised by the outcome of the vote in this activity. For example, some of the positions, such as "Destiny" and "Stay Home," may win votes for their sentimental appeal. Students will also see how presentation can often be as important as content—a point made obvious by watching the speechmakers of today.

Link to Space

As with other kinds of exploration, space exploration usually reflects a combination of personal, political, economic, military, and scientific motives. It also must compete with other activities for approval and resources. The winners of this continual competition change with such factors as the world situation and the economy.

Suggestions

If you want the presenters (and audience) to research their motives, assign their part of the activity several days ahead of the presentations. To divide the labor equally among the class members, you may consider asking the audience members to respond in writing to the questions on page 8.

Why Go?

Student Sheet

Motives for Exploring Space

Colonization

- New beginnings mean new possibilities: We have a chance to start over. We can improve what we have done in the past by building on the knowledge we have gained.
- We can create new cultures and societies and new ways of working together.
- We will increase our understanding of Earth's place in the universe and its (possible) uniqueness.
- We can escape the negative aspects of this world, such as overpopulation and war.
- We will have a place to go if this world system collapses or a catastrophic event occurs on Earth.
- We can monitor Earth's environment more easily from the Moon or another planet where we have a bird's eye view of our home planet.

Curiosity

- Space exploration answers questions, such as: "What can we find using better technology?" "How did our solar system form?" "Where are we going?" "Where have we come from?" "Why are we here?"
- Through exploration, we acquire knowledge and greater understanding of science, the human condition, and our environment.
- Some say space exploration is too risky, but how will we begin to understand and diminish the risks without going forward?
- Asking why we need to explore is like asking why we need to learn, why we need to seek knowledge, or why we need to wonder.
- Increased knowledge broadens our understanding. For example, knowing about only one type of volcano or weather pattern limits our understanding of Earth's volcanoes and weather patterns.

Destiny

- Exploration is inspirational; it drives the human spirit.
- Exploration looks outward and says that society is not limited to one planet.
- We will continue to explore space simply because we can. Imagine future generations looking back at us if we don't explore. They'll see we had the technology, creativity, and leadership—and they'll wonder why we didn't use them to explore.
- Americans have always relished new frontiers. Space exploration is the great frontier of the future.
- The international cooperation in such a venture may bring nations together. We've seen this happen already in Antarctica and with today's space program. Working together should help break down cultural barriers.
- The space program is filled with positive images that create feelings of pride, wonder, excitement, and the belief that anything is possible. It inspires the next generation.
- Exploration means being involved in an enterprise that no one has undertaken before and being the first to discover or achieve something.
- When Neil Armstrong stepped on the Moon, he said, "That's one small step for man, one giant leap for mankind." Our movement into space is a representative effort of all people.

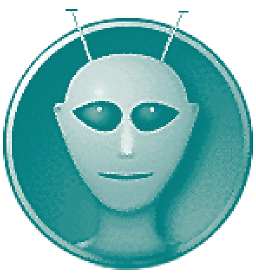
NASM

Why Go?

Student Sheet

Motives for Exploring Space

Search for Life



- If intelligent life forms exist, we can learn from them and they can learn from us. In studying other societies, we also learn more about ourselves.
- Finding out that we are the only ones will be as sobering as finding out we are not.
- Why should we be the only ones?
- Finding extraterrestrial life would be one of the greatest discoveries of all time.
- We may be able to finally answer fundamental questions, such as: “Are we alone?” “Is there life anywhere besides Earth?” “Are other life forms like us or not like us?” “Do they have more advanced technology?”

Economics

- We may find new sources of raw materials. This will diminish competition for dwindling or scarce resources on Earth.
- If we don’t fund exploration, then civilization is not going to grow beyond the bounds that we now know.
- In times of recession, we need to be focused outward, looking for new ventures that will invigorate our industries.
- Space exploration is the kind of challenge that stimulates innovation and could provide the catalyst for economic development. Money spent to explore space is spent on Earth and creates jobs, beneficial spin-off technologies, and demand for new technologies.
- We may find useful materials that don’t exist on Earth.
- Exploration may be the catalyst for developing clean energy resources for Earth that will protect our environment from more harmful forms of energy now in use.
- Tomorrow’s leaders will be the nations that lead the search for extraterrestrial resources and invest in their development.

Stay Home

- Material benefits from space may come some day, but not soon. It’s difficult to estimate what economic opportunities lie beyond Earth, particularly now when space exploration is so expensive.
- In times of recession, we need to gather and protect our financial resources.
- Too many people don’t have the basics—we can’t afford frills like the space program.
- Our destiny as a species is right here on this planet.
- It is senseless to spend billions exploring space when we know so little about this world.
- Exploring other worlds is not a responsible endeavor for people who have not learned to deal with their own environment. If this planet is suffering, we have an obligation to stay here and do what we can to fix it.
- We may encounter unknown risks that might harm cultures on Earth.
- First, we need a clear mission to define why we should explore space.
- As the last great frontier, space could actually fracture relationships between competing nations bent on exploration.
- Just because humans have a need to explore doesn’t mean it’s a good thing. Historically, colonization has disrupted or destroyed cultures. Space exploration holds the potential for exploitation.

Wearing Weight

How Muscles Respond in Space

Goal
To get a feel for weightlessness; to learn that muscles lose their fitness in weightless environments

Key Concepts
- Weight is the force of gravity acting on an object.
- Objects seem weightless while in orbit.
- The human body responds and adapts to weightlessness.

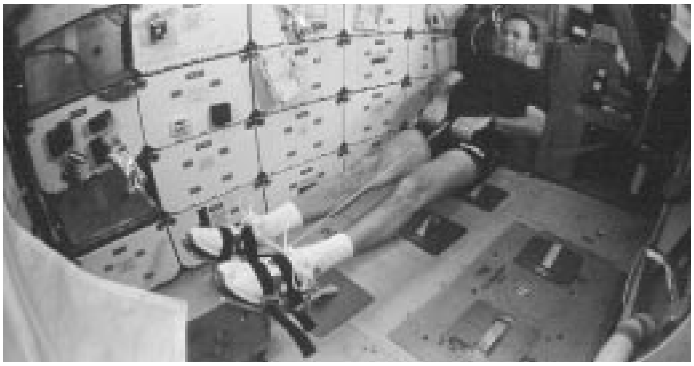
Overview
Our limbs weigh many pounds on Earth, but they behave as though they have no weight at all inside an orbiting spacecraft. In such a relaxing environment, skeletal muscles begin to weaken and become smaller. In this activity, students experience a sense of weightlessness by exercising with leg and arm weights.

Materials
For each student:
One pair of 1/2 kg (1 lb) arm weights
One pair of 1 kg (2 lb) leg weights

Courtesy of Rudy Inc., Toronto

Returning to Earth after months in orbit, this cosmonaut must be helped from his spacecraft. We don't yet know how to control the inevitable muscle loss that occurs in a weightlessness environment. Imagine arriving on another planet in this condition.

Preparation
- Collect or assemble weights as outlined in *Suggestions* on page 14.
- Schedule a larger room if you prefer more space than your regular classroom and you cannot do the activity outside.



© Lockheed/Smithsonian Institution

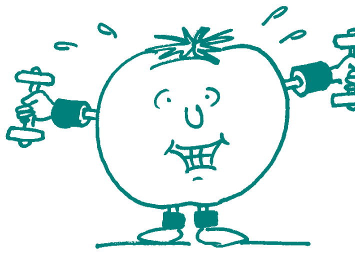
In the weightless environment of the Space Shuttle, Ronald J. Grabe needs no chair as he works out on a rowing machine.

Procedure
a. Attach the weights to your arms and legs.
b. Exercise for about five minutes, doing things that work your arms and legs. For example, you might want to do a series of arm and leg lifts, and then run in place or climb stairs.
c. Record each exercise after you do it.
d. Remove the weights and do the same exercises again.
e. Record your first thoughts right away. For example: What did you notice? What was different? Compare your observations with those of your classmates.

Observe
1. How did the exercising feel in the beginning?
2. How did it feel as time went on?
3. What did you feel like immediately after taking off the weights?
4. What did it feel like to exercise after removing the weights?

Interpret
5. In this exercise you were able to remove a little bit of weight. What would it feel like to be able to remove all of your weight?
6. How would your muscles change if you wore arm and leg weights every day?
7. How would your muscles change if you lost a lot of weight?

Wearing Weight



Apply

8. How would your muscles change if you had to lie in bed for two weeks?
9. Why don't astronauts use weights to help them exercise in space?
10. List two kinds of exercise that would work well in space.

Problem

11. Figure this out: An astronaut weighs 72 kg (160 lbs) and is wearing a space suit that weighs 108 kg (240 lbs). What fraction of his weight is he wearing? Could he walk on Earth wearing this suit?

More Ideas

Design a workout center for use in a weightless environment. Remember that free weights will not provide much resistance, so you will have to think of other things for your muscles to work against. Illustrate your ideas or build a small model.

In the Film

The film shows astronauts using rowing machines and other types of exercise equipment that have been designed for weightlessness. You'll also see the debilitating effects of weightlessness as a Russian cosmonaut returns to Earth's gravity after one year in space.

To the Teacher

Exercising with weights to explain weightlessness may seem odd until the students actually try it. The trick comes when they remove the weights and begin exercising again immediately.

As soon as the weights are removed, the students may feel as if they are floating or as though a force is pulling their arms upward. This sense of weightlessness makes the second set of exercises seem much easier, but only briefly. This effect wears off quickly, so encourage the students to start exercising again as soon as they remove the weights.

If students were able to remove all of their weight, their muscles would seem unnaturally strong. The sensation would be similar to swimming in water without the surrounding water resistance—a sensation that astronauts know well.

If students wore arm and leg weights every day, they would increase their muscle size, strength, and endurance. Conversely, if they lost a significant amount of weight, their muscles would become smaller and weaker unless they exercised more.

Muscles also become smaller and weaker if they are not used for a period of time, such as when a person is confined to bed or is living in a weightless environment during space travel. A bedridden person is not likely to exercise much, but astronauts do work out while they are in space. This reduces the problems they have upon returning to Earth's gravitational environment.

Astronauts don't exercise with weights because objects in space are effectively weightless. Instead, they stretch elastic cords and perform isometric exercises. *Note:* This activity does not discuss the resistance that all mass has due to inertia.

The weightlessness of objects in space also explains how astronauts can wear space suits that are one and one-half times their own weight. It would be nearly impossible to walk with such a load on Earth.

Link to Space

On Earth, our muscles retain their strength and mass because they are constantly working against the resistant forces of our daily activities. When a 43 kg (95 lb) student walks, he or she carries that weight everywhere he or she goes. In the weightless environment of a spacecraft, an astronaut's muscles lose strength and mass because they don't have to support or work against the weight of the body.

Wearing Weight

Postural, or weight-bearing muscles, lose the most strength and mass. Some muscles change their character; postural muscles begin to resemble locomotion muscles as fast fibers replace slow fibers. Muscles associated with fine movements (such as blinking or handwriting) do not change. Bones also change because they work together with the muscles to create movement. The changes in bones and muscles seem tied to loading, or the amount of force that each is subjected to.

Although exercising in space helps to reduce the loss of fitness, some loss seems to be inevitable. Researchers are searching for effective, safe exercises that astronauts can do. They are currently testing workouts that include treadmills, stationary bicycles, and resistive exercise with elastic cords.

NASA JSC S-83-37627

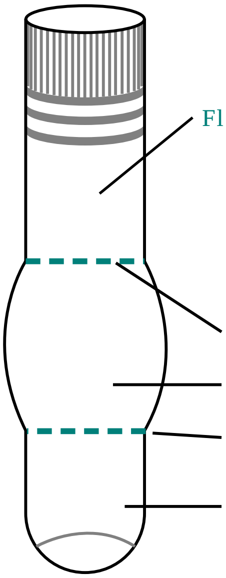
With William Thornton's help, Guion Bluford tests the Space Shuttle treadmill on Earth. Once in orbit, he will need the straps to keep his feet on the platform.

Suggestions

You may want to coach your students through this activity. First, make the activity enjoyable. Consider using a children's exercise record or video to focus the students and standardize their exertion. Second, explain that the exercises will get easier. Third, remind them not to overdue the exercises. They don't need to wear themselves out.

You can make arm and leg weights from socks filled with small bags of sand, metal washers, or rolls of coins.

You can also give students small dumbbells or soup cans to hold. Whatever you use, limit arm weights to 0.5 kg (1 lb) and leg weights to 1 kg (2 lb). Alternatively, students can fill backpacks with about 4.5 kg (10 lb) of books. Check the loads—students have a tendency to overload backpacks.



Ears, Eyes, and Toes

How You Keep Your Balance

Goal

To explore the different senses we use to keep our balance in Earth's gravitational environment

Key Concepts

- Except when we are lying down, our muscles constantly work to keep us from falling.
- Three sensory systems (involving the eyes, inner ear, muscles and joints) work together to help us keep our balance.
- Human sensory systems are designed to work in Earth's gravitational environment.

Overview

Our senses and brain work together so that we can keep our balance in Earth's gravitational environment. Three main kinds of sensory information are used by humans to detect position and motion. Sensors located in our eyes, muscles and joints, and inner ears work together to help us detect position and motion so we can keep our balance. You'll explore how these three sensory systems work in the following exercises.

Materials

Stop watch or clock with second hand
Rotating chair(s)
Blindfold (optional)
Student Sheet on page 20

Preparation

- Borrow rotating chairs from office workers, the computer center, or any class that might have them.
- Copy *Student Sheet*, one for each student.
- Bring in scarves or strips of material for blindfolds.

Procedure

a. Working with a partner, take turns doing the following:
   i. Try to stand on one leg for one minute.
   ii. Try this several times, recording the time if less than one minute.
   iii. Calculate your average time.
b. Repeat *step a* with your eyes closed.

Questions

1. Describe any movement you notice as you or your partner take turns trying to stand on one leg.
2. What do you think is causing the movement in your leg?
3. Can you stand on one leg longer with your eyes open or with them closed? Is this true for your partner?
4. Which sensory system(s) is this exercise investigating?
5. How important is vision in helping you keep your balance?
6. What type of people might be better at this exercise?

NASA JSC S40-210-008

Millie Hughes-Fulford tests her awareness of her position. With eyes closed, she tries to point a penlight as Rhea Seddon records information. Similar tests are done on Earth for comparison.

Ears, Eyes, and Toes

Try This

Tonight as you are drifting off to sleep, lie very still with your eyes closed. Try to determine the positions of your hands and feet without moving them. Without opening your eyes, move one of your hands. Was it where you thought it was?

What's Going On?

Our brains rely on signals from nerves within the body's eyes, muscles, joints, and skin to determine the position of our limbs. The brain cannot always precisely determine where the limbs are without signals to the nerves from external stimuli (visual objects, air turbulence) or internal cues provided by muscle movement.

Astronauts report that in space they are not as aware of the position of their limbs as when they are on Earth. They "lose track" of their limbs. What causes this? On Earth, our muscles stimulate nerves that send information to our brains about where our limbs are. When a person enters space, their limbs become weightless—nerves that are accustomed to continual stimulation from the weight of limbs suddenly are without this stimulation . This lack of stimulation may cause this "losing track" of limbs.

Part B

Procedure

c. Have a classmate sit with eyes closed and legs crossed on a chair that can rotate.
d. Read these instructions to your classmate:
   i. Place your fists on your knees with your thumbs pointing up.
   ii. Lean your fists left or right to show the direction you think the chair is moving.
   iii. Open your eyes when you think the chair has stopped turning.
e. Push the chair so that it begins to slowly rotate. Use smooth and gradual movements, be quiet, and don't touch your classmate. Stop pushing after 10 turns, letting the chair slow gradually.

Questions

7. Could your classmate tell when the chair had stopped?
8. What happened when your classmate's eyes opened?
9. How might the results be different if your classmate's eyes had remained opened?
10. Which sensory system are you "fooling" in this activity?
11. Would this activity work in a weightless environment?

Try This

Place about 3 cm (1 in) of water in a clear glass. Place the glass on an overhead projector. Sprinkle some chalk dust on the water, and focus the projector on the dust. Gently rotate the glass without lifting it. Watch the dust on top to help you "see" the motion of the water in relation to the glass.

What do you notice about the water as you start rotating the glass? As you continue rotating the glass? When you stop rotating the glass?

What's Going On?

The glass represents the inner ear's semicircular canals and the water represents the fluid inside these canals. (The dust simply makes the water motion easier to see.) The water does not begin to move as soon as the glass is rotated, but it soon catches up and rotates with the glass. When you stop rotating the glass, the water keeps circling.

To test her inner ear responses, Roberta Bondar spins in a chair while cameras and other devices record her reactions.

This demonstrates *inertia*. Inertia explains why rotating objects continue to rotate until an outside force stops them. In this example, the object was water. The force was provided by your hand and friction between the glass and water.

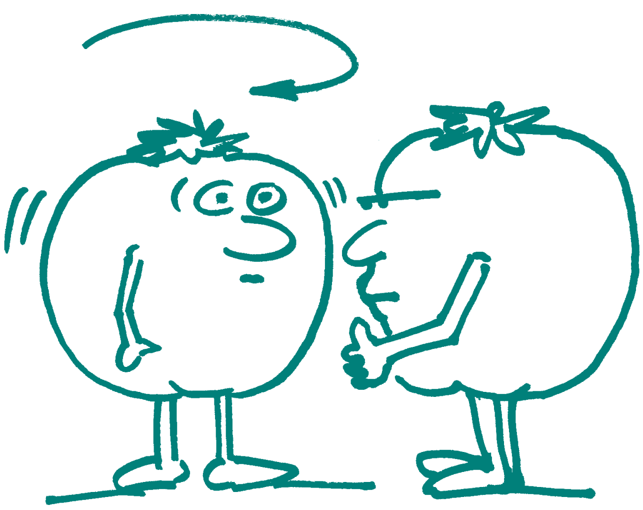
Ears, Eyes, and Toes

Procedure

f. Move your head from one side to the other while doing the following: Stare straight ahead, trying to keep your pupils in the center of your eyes. Have your partner watch your eyes carefully as you turn.

g. Switch roles and repeat *step f*. Record your observations.

h. Repeat *step f* with your eyes closed, while gently holding your fingers on your eyelids so you can feel if your eyes are moving beneath the lids.

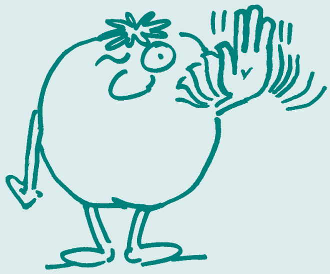


Questions

12. How did your partner's eyes move while turning?
13. Did your eyes move while you turned, even when they were closed?
14. What sensory system is causing this eye motion? (*Hint*: Refer to your answer in *question 13*.)
15. If you have ever watched dancers or skaters spin rapidly, you may have noticed that they move their heads in a distinct way. How is that movement similar to this activity?
16. How might the eye movement you described in *question 12* be related to keeping your balance?

Try This

Hold your hand at arm's length and watch your fingers as you rock your hand side to side from the wrist. Start slowly, then speed up. What do you notice?



Now hold your hand still and shake your head back and forth while watching your fingers. Start slowly, then speed up. What's different this time?

What's Going On?

In the first case, a tracking reflex in your eyes helps you focus on your fingers when they move slowly. This reflex can track up to 60° of movement per second. As the fingers move faster than that, they look blurry.

The second case involves a reflex between the inner ear and eye. This reflex helps your eyes stay still even when your head is moving. This reflex can follow much faster movement than the tracking reflex.

Glossary

Semicircular canal—structure in the inner ear that detects changes in the head's rotation, and that helps maintain a sense of balance and orientation. (See page 20 for more information.)

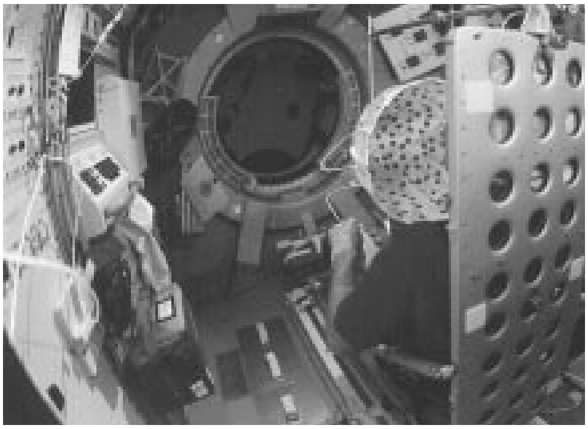
Ears, Eyes, and Toes

More Ideas

- The following posture test—called a Rail Test—has been done on astronauts before and after going into space. Stand on a narrow board (such as a 2 x 2) with the toe of your back foot touching the heel of your front foot. Fold your arms across your chest. How long can you stand like this with your eyes closed? With your eyes open? (*Note:* The board should be long enough so that two students can hold it firmly on the floor, one at each end. Enlist two more students to act as spotters.)
- Predict how people will do on the balance test in *Part A* and test your theory. Find several people who use their eyes a lot in their work, such as TV camera operators, visual artists, or scientists who use microscopes. Compare their results with people who need balance for their work, such as dancers, construction workers, or athletes.

In the Film

A rotating, spotted umbrella fills the screen and gives the viewer the perspective of an astronaut investigating the causes of motion sickness. How do you deal with the conflicting stimuli of watching the moving dots while sitting still?



In this experiment, Ulf Merbold uses a spinning dotted bowl to investigate the causes of motion sickness. He sees moving dots, but he feels stationary. He will compare this test to those he makes on Earth.

To the Teacher

This activity explores the three sensory systems—eyes, muscles and joints, and inner ear—that help us keep our balance. Humans can keep their balance if any one of these systems is impaired, but not if two are damaged. The exercises focus on different systems but cannot isolate them.

The exercises can be done in sequence or separately. Please discuss the cautions for *Parts A* and *B* with your students to ensure the exercises will be enjoyable, effective, and safe.

Part A

Caution—Be sure students "spot" each other in this exercise. Have them work in pairs with one person performing the test and the other standing by in case the performer topples. If possible, have the students do this exercise in a clear space with a soft landing.

This exercise focuses on the sensory system in the muscles and joints and looks at the role that vision plays in this process. As students do the exercise, they will sway back and forth as they try to keep their balance while standing on one leg. Most of the movements in the standing leg are tiny and rapid and are more easily felt in your own body than observed in another person. If any students have bare legs, though, look for the muscle contractions.

These movements are caused by nerves within muscles and joints that are constantly sending messages to the brain to keep you from falling. When you start to tilt to

Ears, Eyes, and Toes

the left, nerves in your leg muscles signal your brain, which then sends a message to other muscles, which contract and pull you to the right. Once you start to tilt to the right, nerves in your leg muscles signal your brain, which then sends a message to muscles to pull you to the left. This process occurs continuously when we are standing or sitting, but we are much more aware of it when we are standing on one leg.

For most people, vision is the most important sensory system in maintaining balance because it provides much of the information we obtain about the world around us. People who rely more on vision than the other sensory systems mentioned here have a more difficult time maintaining equilibrium with their eyes closed than people who have well-developed muscular-joint postural reflexes. Reflexes improve with use and deteriorate with disuse. Through experience, your brain and muscles learn more precise control of muscle contractions, which is why older children are better at this than younger ones. Dancers and other individuals who rely on good balance are usually better at this exercise also.

Part B

Caution—Do not use students who are prone to motion sickness! You may wish to have a couple of volunteers demonstrate for the class. If students work in small groups or pairs, make sure they spot the spinner and don't push the chair too fast. The chair does not need to be spun at high speeds to get good results. After spinning, encourage the volunteers to stay seated for a few moments or to shake their heads gently to regain equilibrium.

Some people are terrific subjects and can be fooled quite easily. Others might know exactly whether or not the chair is turning or in what direction it is turning. (Be sure the students pushing the chairs are quiet so the spinning students cannot use cues of sound or touch. Be sure the students being spun keep their eyes closed.)

This exercise focuses on the sensory system in the inner ear and looks at the role vision plays in the process of balancing. Semicircular canals deep inside each ear detect the head's rotation. Without additional cues from eyes and muscles, the inner ear can be fooled into thinking that it is moving when it is not and vice versa. (Refer to *Student Sheet*, page 20, for a more detailed description of how the semicircular canals sense motion.)

Astronauts have performed similar experiments on *Skylab* and Space Shuttle missions. The experiment works fine in a weightless environment because the semicircular canals primarily detect rotational movement, not gravitational forces. To do the exercise, though, both the chair and astronaut had to be strapped down!

Part C

This exercise focuses on the sensory system in the eye and looks at the role the inner ear plays in this process. Students should work in pairs, one doing the exercise while the other observes. Observers should see their partner's eyes making short, jerky movements. When students repeat this activity with their eyes closed, they should feel this movement under their eyelids.

What is happening in this exercise? When your eyes are closed they cannot be receiving visual signals. Another sensory system—the inner ear—is telling your brain that your head is turning. When your brain receives these signals, it sends signals to the eyes making them move in this jerky way.

This reflex helps steady the visual field—the eyes "grab" the visual scene for a moment, let go and jerk forward, "grab" again, let go, and so on. This helps you keep your balance when you turn your head. Spinning dancers or skaters do this with their entire head. As they spin, they stare at one spot. When their head can't hold the position anymore, they jerk their head around to see the spot again. "Spotting" helps dancers and skaters keep their balance.

Link to Space

About 80 percent of astronauts experience symptoms similar to motion sickness when they enter a weightless environment. This nausea may result when the brain receives signals from its sensory systems that do not

Ears, Eyes, and Toes

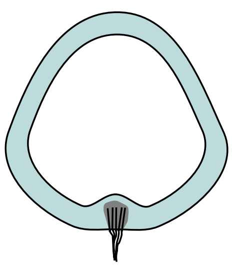
match familiar patterns. For example, in an orbiting spacecraft, the brain receives signals from the eyes that it normally associates with being in a static environment, but at the same time it receives signals from the inner-ear system that the body is falling. This “sensory conflict” theory is the most widely accepted explanation for space motion sickness. (Incidentally, a similar theory is widely accepted to explain motion sickness on Earth, although the symptoms are slightly different.)

Student Sheet

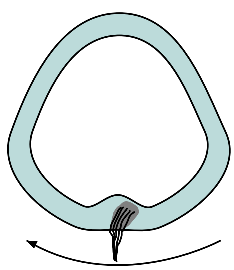
Postural reflexes improve with use and deteriorate with disuse. Since astronauts do not use their postural though, most of them are acclimated as their brains get used to the new combination of signals.

Today, many astronauts take motion sickness drugs when they start to feel sick in space. Within 72 hours, used to the new combination of signals. reflexes during space flight, these reflexes become sluggish and the astronauts perform poorly on posture tests when they first return to Earth. Recovery is quick, however, and they return to preflight performance within two to four days.

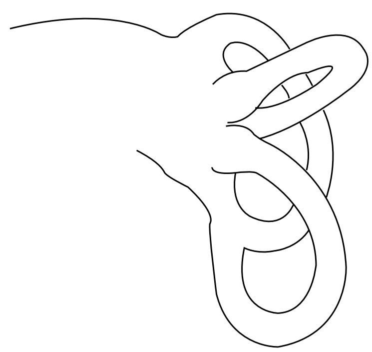
Inner Ear



Stationary or resting position



As head turns to the left, fluid in the canal lags behind and hair cells are bent to the right



Three semicircular canals, each in a different plane

Semicircular canals in your ears allow your sensory system to detect when you are rotating. Each ear has three canals, and each canal is on a different plane. These different orientations detect any possible rotation.

The diagram shows the cross section of a semicircular canal. Fluid in the canal is lightly shaded. The cupula, which acts like a float, is shaded dark gray with hair cells embedded in it. When your head turns, the canal turns with it, but the fluid lags behind due to inertia. (Remember what happened when you turned the glass of water?) The cupula is displaced by the lagging fluid and bends the hair cells. The hair cells send messages to the brain that your head is rotating in a certain direction.

If you keep turning in the same direction, the fluid catches up and moves at the same speed as the hair cells and will no longer bend them. You’ll think you have stopped moving unless your eyes or muscles provide additional cues. If you stop spinning abruptly, the fluid in the semicircular canal keeps going and bends the hair cells in the opposite direction. Now, your brain senses that you have started moving in the other direction.

Note: These activies do not address how humans sense gravity and straight-line motion, which is associated with separate structures in the inner ear.

Faraway Feelings

Isolation and Separation

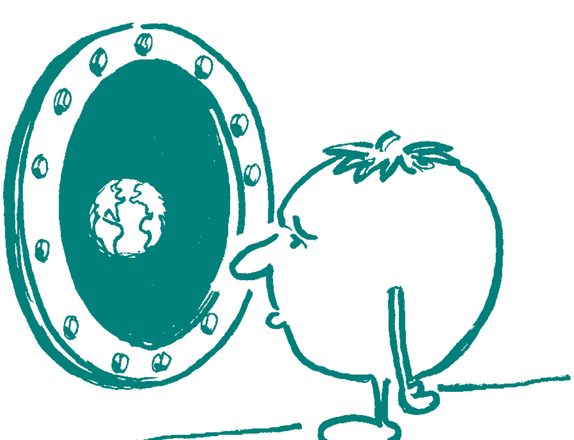
Goal
To increase students' awareness of the separation and isolation an astronaut feels on a long assignment

Key Concepts
- The people, things, and activities that are a part of your daily life define your cultural comfort zone.
- Emotional unrest often occurs when you leave these familiar people, things, and activities.
- On long missions, astronauts must deal with difficulties caused by isolation and separation from loved ones.

Overview
A one-way trip to Mars will take at least nine months. What will happen to astronauts psychologically during such a journey? How much anxiety will they feel when they are separated from their family, friends, and culture? In this activity, students explore these questions.

Materials
Questionnaire on page 23

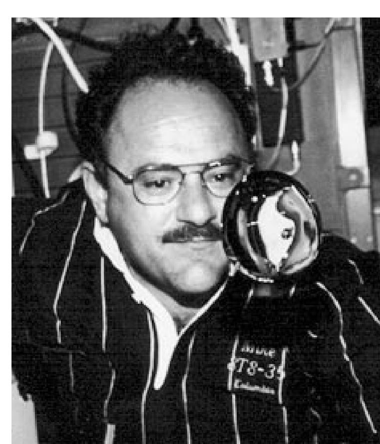
Preparation
Copy *Questionnaire*, one for each student.



Procedure
Complete the *Questionnaire* and answer the following questions.

Questions
1. How did you feel as you filled out the *Questionnaire*?
2. Consider the items you chose for *part e*: What might you have included if you had packed this "trunk" three years ago?
3. Do you think you will still enjoy these things in the future?
4. How can people prepare for long absences from loved ones and a familiar culture?
5. Many people move from their family and culture to take a new job. How do you think their feelings affect their work?
6. Astronauts maintain a precise schedule—even their free time is allocated. How might this affect their emotional state?

Glossary
Cultural comfort zone—the people, things, and activities that are a regular part of your life.



NASA 91-HC-23

Today's astronauts devise simple forms of diversion. Here, John Lounge plays with water that behaves much differently in a weightless environment than it does on Earth.

Faraway Feelings

More Ideas

Think about when you have been out of your cultural comfort zone—times when you have moved, traveled, or visited friends or relatives who live in a different kind of neighborhood than you. How did you feel? How did you deal with these feelings?

In the Film

As you watch astronauts working on the Space Shuttle, look for ways in which space and thus privacy are limited on the craft. For example, how many activities can you identify in a single location? Where do astronauts sleep?

© Lockheed/Smithsonian Institution

Tiny cubicles, such as this one being used by Bill Readdy, provide a little privacy on board the cramped Space Shuttle.

NASA 83-HC-590

Typically astronauts share sleeping quarters as Guion Bluford (left) and Richard Truly are doing on board the Space Shuttle. As space flights lengthen, the compatibility of crew members becomes increasingly important.

To the Teacher

Discuss the *Questionnaire* with your students before they begin, reminding them that there are no right or wrong answers and that many people have trouble answering these questions. Nevertheless, encourage them to answer as specifically as possible. In addition, discuss the importance of personal mementos, and the ways students would record their experiences on the journey.

Predicting who and what you will miss the most is difficult, even if you have moved several times. Most students are close to more than five people, and if they are socially active, they may have a hard time rating which activities they'll miss the most. Even if the student answer the questions easily, they may not have thought about the fact that our ideas and tastes change with time. In the discussion, talk about the concepts of timelessness and trendiness in music, literature, and recreational activities.

Discuss the idea of cultural comfort zones. Which students have left their cultural comfort zones? Examples include visiting relatives in another part of the country, attending a new school, and moving to another region of the country. Invite someone to the class who has traveled extensively or lived in different cultures to discuss how people prepare themselves for such changes. How do they learn about their new homes? How did they deal with emotions—positive and negative—that arise when people leave their cultural comfort zones?

Faraway Feelings

Common ways include taking some of their culture with them, learning to enjoy what the new culture offers, and maintaining close contact with friends in their former culture. Staying busy may also help by providing a stable routine and a sense of accomplishment.

Link to Space

Focus the discussion on the space program by asking what cultural changes astronauts might experience on a long space journey. On the trip to Mars, the new culture would be one the astronauts form themselves.

During today's short space missions, isolation is brief and is offset by preparing crews to work as teams for about a year before flight. But astronauts have experienced the tension of separation and isolation during longer missions in the past: cosmonauts aboard the space station *Mir* for one year and astronauts spent three months aboard the orbital workshop *Skylab*.

Because of these experiences, NASA's Human Factors Program looks at a variety of important psychosocial issues. For example, they study how people establish authority structures, how loneliness and isolation affect sleep patterns, and how colors and patterns affect a person's emotions and work.

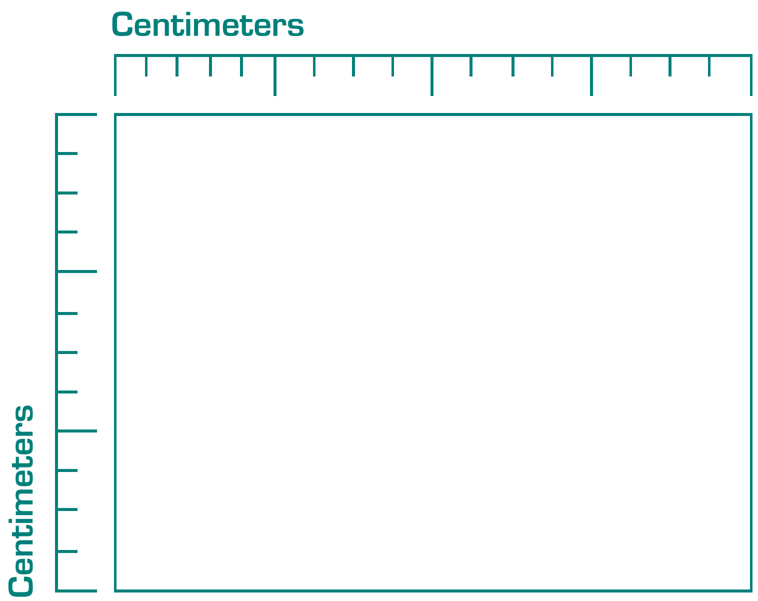
Astronauts who travel to Mars could still communicate with Earth, but they would have to get used to a four- to twenty-minute delay in transmission, depending on the planets' relative positions. How might such delayed communication affect astronauts psychologically? For example, how would they feel discussing a family or mission crisis under such conditions? What would it be like having normal conversations with only crew members? Training procedures for Mars-bound astronauts haven't yet been established. Ask your students how they would prepare people chosen for the long journey to Mars.

Student Sheet

Questionnaire

Imagine you are an astronaut chosen for the first trip to Mars. You will be gone for three years and you will live with five other astronauts. With that in mind, answer the following questions:

a. What five people will you miss the most?
b. What five recreational activities will you miss the most?
c. What five places will you miss the most and why? Be specific.
d. What five foods will you miss the most and why? Be specific.
e. Space aboard the craft is limited and new supplies cannot be sent to you. You have one personal locker that measures about 1 meter x 75 cm x 25 cm (3 ft x 2 ft x 10 in). Choose items you will put in the locker (consider reading material, music, personal mementos, and photographs). Make sure they fit by drawing them to scale at right.



Telescopic Eyes

What Makes Good Viewing?

Goal

To understand how atmospheric conditions affect astronomical observations made from Earth

Key Concepts

- Air turbulence, clouds, and foreground light levels affect how we can see distant objects from Earth.
- Telescopes can be placed on mountains to minimize the effects of Earth's atmosphere on viewing.
- Telescopes placed in space are not affected by Earth's atmosphere.

Overview

Optical telescopes gather light reflected or given off from objects in space. The atmosphere can greatly affect how this light travels from the object to the telescope. In this activity, students investigate three effects of the atmosphere on astronomical observation: air turbulence, cloud cover, and foreground light level.

Materials

For each group:

Binoculars	Poster board
Hot plate	Newspaper
Small lamp	Dry ice
Blanket	Wooden or plastic spoon
Pin	Shallow plastic dish of water

Part A

Preparation

- Tape a piece of newspaper to your classroom wall opposite from where you will be using the binoculars.
- Set up the hot plate a few feet in front of where you will be standing, just below eye level, so that you will have to look at the newspaper through its heat.

Procedure

a. Using the binoculars, focus on the newspaper from across the room. Steady the binoculars—put the binoculars on a tripod or stack of books, or rest your elbows on the table.

b. While you focus on the print, have someone turn on the hot plate.

c. Have someone turn off the hot plate while you continue to look through the binoculars.

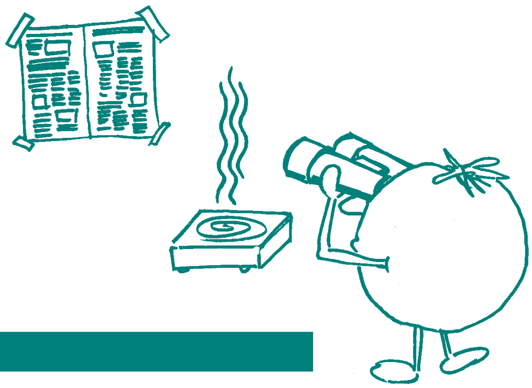
d. Repeat the procedure until everyone has tried it.

Observe

1. How did the newspaper look at first?
2. What did you notice while the hot plate was on?

Interpret

3. How do you think the heat affected your viewing?
4. When viewing stars at night, what might cause a similar effect?



Part B

Preparation

- **Caution**—Touching dry ice will cause severe frostbite. Use only plastic or wooden utensils. Students working with dry ice should be closely supervised.
- Using a pin, poke a number of holes in a piece of poster board and tape the poster board so that it hangs from the edge of a table. Place a small lamp under the table, behind the poster board. Drape the table sides (and around the poster board) with a blanket so that the light shines only through the holes.
- Test this activity ahead of time. If the room cannot be made dark enough to give good results, you may have to find another location for this activity.

Telescopic Eyes

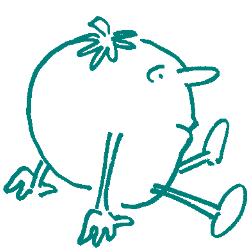
Procedure

e. Make and set up the star field as described in the *Preparation*. Fill the dish with warm water and place it on the table just above the star field. Turn on the small lamp and view the "stars".

f. Using a plastic or wooden spoon, place five or six chips of dry ice in the water. (A thick white mist of water will bubble out of the dish and fall in front of the "stars".)

g. Look at the "stars" through the mist. How do they look now?

h. Shine a flashlight on the mist and describe what you see.



Observe

5. Describe how the "stars" looked at first.
6. How did the "stars" look when viewed through the mist?
7. How did the stars look when the flashlight was on?

Interpret

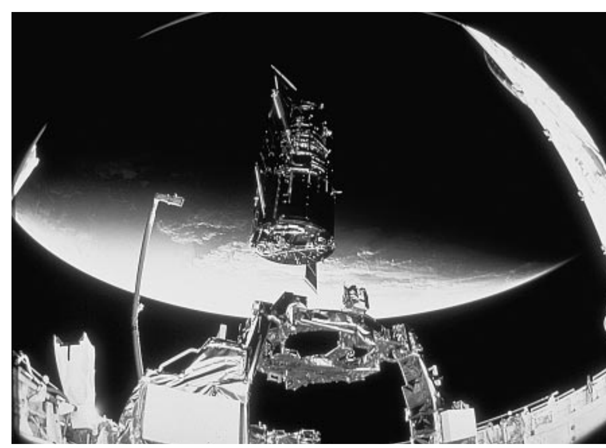
8. How do you think the mist affected your viewing?
9. When viewing stars at night, what might act like the mist? The flashlight?

Apply

10. Based on this activity, make a list of some of the atmospheric qualities needed for good viewing with optical telescopes.
11. What places might have these qualities, making them good spots for viewing?
12. What are some of the advantages of putting telescopes in orbit around Earth?

More Ideas

- List advantages and disadvantages of space telescopes such as the *Hubble Space Telescope*.
- Organize a class field trip to an astronomical observatory.
- Research light pollution and how astronomers deal with it.



In April 1990, the *Hubble Space Telescope* was deployed from the cargo bay of the Space Shuttle. Telescopes placed in Earth orbit can collect any type of light without atmospheric disturbance.

In the Film

Spectacular footage of the *Hubble* shows the launch, deployment, and subsequent servicing and repair of this orbiting observatory. Viewers also learn about the role that Earth-based telescopes play in space exploration.

To the Teacher

Please note: Due to time constraints this particular activity was tested by the author only; it was not field-tested in the classroom. We encourage you to adapt it, along with all the others, to your particular needs.

Viewed through binoculars, the newspaper should appear larger and clearer than it does with the naked eye. The print appears to move while the hot plate is on, but stabilizes when the hot plate is turned off. This effect is magnified by the binoculars, but can be clearly seen with the naked eye.

Telescopic Eyes

Earth's atmosphere is naturally turbulent. It contains many air pockets, which have different densities, and that are in constant motion. The hot plate enhances this air turbulence. Heating and cooling affects air's density, and air's density affects how light passes through it. Light normally travels in straight lines, but will bend if it encounters a pocket of air with a different density.

The path of light from the newspaper is shown in Fig. 1. Because the light hits your eye at an angle, it appears to be coming from *A*. In the next instant the pockets of air shift, causing a ray of light from the same spot to take a different path to your eye (Figure 2). This time, the object seems to be at *B* and looks as though it is moving. This is especially noticeable when the air is being heated.

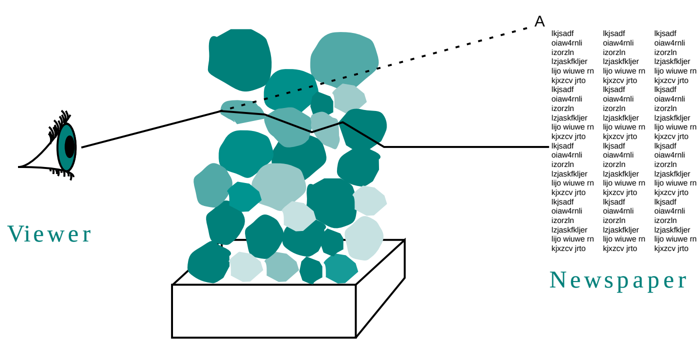
You've witnessed this effect if you've ever seen stars that appeared to twinkle, or seen "heat waves" rising from a hot road or beach. This phenomenon is so noticeable when looking through the plume of jet exhaust that movie directors often film it. Air turbulence caused by temperature differences affects our star gazing in much the same way.

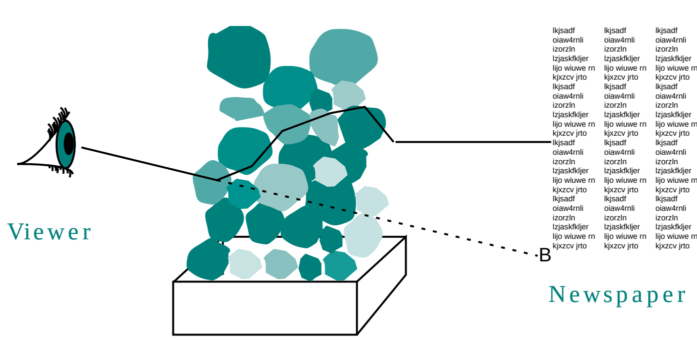
In the dark, the "stars" are pinpoints of light and are easy to see. Viewed through the mist, the "stars" look dimmer and somewhat fuzzy; some may disappear altogether.

Dry ice gives off cold carbon dioxide gas, which condenses water vapor in the surrounding air. The resulting cloudy mist blocks some or all of the light. Atmospheric particulates, clouds, mist, and fog interfere with nighttime viewing in much the same way.

When the mist is lit by the flashlight, the "stars" (especially the dimmer ones) seem to disappear. The brightness of the stars is not changing—a blanket of illumination, between them and the viewer, decreases the contrast and makes them less noticeable. Similarly, moonlight and city lights can substantially interfere with star gazing even on a clear night. People are often amazed by the number of stars they can see from a dark countryside—literally thousands under ideal conditions. The stars are always shining in the sky, even in the daytime; the lighted atmosphere, however, decreases the contrast, making them difficult to see. The darker the atmosphere, the more stars you can see.

When you view any object from Earth, you have to look through an "ocean" of air. Since the air is thicker at sea level than on mountain tops, optical telescopes used in research are intentionally placed at high altitudes to minimize the effects of Earth's atmosphere. Placed on high mountains, optical telescopes contend with less light from nearby cities and less atmospheric disturbance, such as air turbulence and clouds, than they would at lower, warmer locations. Telescopes designed to collect infrared light must be placed on high mountains where the air is extremely dry since water vapor substantially absorbs this type of light. The atmospheric conditions on mountains in Arizona, Hawaii, and northern Chile make these locations some of the best for viewing objects in space through optical telescopes.





Telescopic Eyes

Link to Space

Only some types of electromagnetic radiation (notably visible light, infrared, and radio waves) can easily get through Earth's atmosphere. Short wavelength electromagnetic light such as gamma and x-rays is substantially absorbed by Earth's atmosphere. To observe the universe using these types of light, astronomers must use specialized observatories in space. Placing a telescope in space is like finding the ultimate mountain top—in space there is no atmosphere to disturb light coming from distant objects.

Suggestions

Part A cannot be done well if the room is warmer than 80˚F. Cardboard tubes can be substituted for the binoculars, but the effects will not be magnified, and will not be as noticeable. Mounting binoculars on a tripod will stabilize students' viewing as well as allow them to take turns more easily.

In *Part B* use plastic or wooden utensils when handling dry ice—never metal or glass. If you choose to do this activity as a demonstration for the class, have students file past the apparatus because they need to be within a few feet of the star field to make accurate observations. Experiment with the size of the holes in the poster board; "stars" should not be bright enough to light the mist in the darkened room. The mist should obscure the "stars" rather well and the lighted mist should make most of them invisible.

Robotic Guides

Preparing for Human Exploration

Goal
To analyze data from robotic explorers

Key Concepts
- Robots are often sent into space before humans to gather data.
- Robots generally are cheaper to send into space than humans.
- Robots are better equipped to handle dangerous or repetitive tasks.

Overview
Since the launch of *Sputnik* in 1957, robotic craft have always preceded humans into space. As we plan exploration beyond the Moon, the role played by robots continues to be invaluable. In this activity, students study images and data from one of eight locations in the solar system, and determine the practicability of sending astronauts to the site.

Materials
Site Data on page 32
Student Sheets on pages 33 and 34
Presentation Checklist on page 31
Site-specific Information on page 31 (for the teacher)

Preparation
- Copy the photos and mount them if you wish.
- Enlist other teachers as “Institute Officials” for the presentations.

Procedure
a. *Have a volunteer read aloud: (Imagine that you are a visiting scientist at a prestigious planetary research institute. Robotic spacecraft, launched years earlier, are now sending pictures and information about a number of interesting sites in our solar system. Officials at the institute have asked your team to study the data and give recommendations regarding the practicability of sending a human expedition to one site. A winning argument can be made for each site, regardless of its problems. Your arguments should be comprehensive and should demonstrate your awareness of the major issues.*

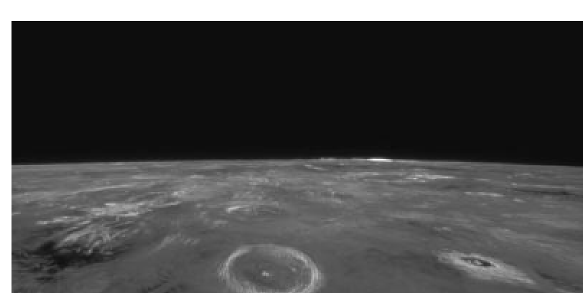
b. Divide into groups of four and take on the following roles: Scientist (S), Medical Consultant (M), Engineer (E), and Project Coordinator.

c. Distribute the site photographs, one to each team of four students.

d. Study the image and data received from your site, using the questions to guide your observations.

e. Address each question; pay special attention to those marked by your role’s initial. For example, if you are the Medical Consultant, look for questions followed by (M). The Project Coordinator can synthesize findings and begin preparing the presentation.

f. Present your site evaluations to the institute official(s).



NASA JPL

Three-dimensional images were constructed from *Magellan* data for the fly-over sequences in the film. *Magellan’s* radar peered through the dense atmosphere of Venus to map the surface. (Note: Only the surface is shown, the Venus’ “sky” is not dark during the day.)

Robotic Guides

Questions

Which of the following could you study at your site: atmosphere (weather), volcanoes, impact craters, or faults? (S) What on-site resources might be useful to the astronauts? (E)

Does your site exhibit characteristics that make surface exploration by humans especially difficult or even impossible? (S) For example, humans cannot withstand long-term conditions of greater-than-Earth gravity or intense heat. What are your recommendations? (M)

In our solar system, only Earth's atmosphere can sustain human life. Aside from the need for air for life support, how might future explorers contend with atmospheres that have more or less pressure than Earth's? (E, M) Can you give examples of prior exploration experience that might be valuable? (S)

What challenges faced by space travelers increase as time spent in space increases? (M) How might your site's distance from Earth affect communication between crew members and people on Earth? (E, M) How will the length of a mission affect the kind of equipment needed and limit the kind of equipment you can take? (E) What affects the cost of traveling to your site? (S)

More Ideas

- Compare two or more sites that might be considered for a human mission.
- After completing this activity, post the images on a school bulletin board and host a contest to identify each location.

In the Film

Destiny in Space features images of Jupiter returned by the *Voyager* probes. Viewers also "fly" above the surface of Venus and Mars in three-dimensional scenes developed using data sent by the robotic explorers *Magellan* and *Viking*.

To the Teacher

Students should notice evidence of these planetary features: *Sites A, B, D, E,* and *G* have atmosphere; *D, G,* and possibly *H* show volcanoes; *C, E, F, G, H,* and possibly B show impact craters; and *B, C, E, F,* and *G* show fault lines.

Soil is one possibility of an on-site resource that might be useful. For example, Martian and lunar soil could be used for growing plants. Soil could also be used as a radiation shield if the crew had some way of digging into it. If a planet had frozen water, that could be a source of drinking water if it was mined and purified.

Within the limits of today's technology, humans could not work on Jupiter because they wouldn't survive the attempted landing. Jupiter has high atmospheric pressure, radiation, and gravity twice as strong as Earth's. Scientists could probably develop a way to shield humans from the high pressure, but they wouldn't be able to reduce the gravity or adequately shield explorers from radiation. Even robotic craft would require some specialization. The gas giant has no real surface to land on, so a robotic explorer would have to float or hover in the dense gas of the planet. In light of these facts, Jupiter would probably be studied from orbit.

Venus would also have to be studied from orbit. Its high temperatures are daunting even for robotic craft, and there is no way to provide cooling. Refrigeration would fail because of the planet's high temperature. Refrigerators work by extracting heat from a box and discharging it into the atmosphere. (Students might have noticed that refrigerators are often warm on the outside.) If the atmosphere is too hot, a refrigerator cannot release its heat and the system overheats. More than 10 spacecraft have sent information from the surface of Venus, and all have overheated. *Venera 17* operated the longest to date—127 minutes!

29

Robotic Guides

Sites B, C, E, F, and *H* are cold, rocky sites similar to Antarctica. Unlike Antarctica, however, they have no atmosphere. This lack of air poses challenges similar to exploring the Moon where astronauts had to wear pressurized suits.

Direct exploration of *sites A* and *G* by robotic craft would pose challenges similar to deep-sea exploration. Scientists use remote submersibles to explore the high pressure environment of the deepest oceans. Rigid craft that would be capable of withstanding high pressure would be needed to explore *sites A* and *G*. Prior experience in studying weather, wind, and fluid dynamics would be helpful in analyzing the thick atmospheres of these sites.

Spacecraft traveling on fuel-efficient paths travel slowly, but they require far less fuel than if they were on a fast trip. However, the costs, risks, and engineering challenges of space travel increase with mission length. Students should be able to identify the following factors that would affect cost and feasibility of a mission to their site: Difficulty of engineering appropriate spacecraft, difficulty of communicating across the vast distances of space, physiological and psychological adjustments, and environmental risks such as radiation and micrometeoroids. A discussion of these factors continues in the following section.

Even though long missions present expensive engineering challenges, they will probably cost less per day than short missions. They also will be able to accomplish long-term research that is impossible on short missions.

Link to Space

A variety of engineering and medical challenges must be met before humans can travel in space for extended periods. Spacecraft designed for long missions will be closed systems—no supplies will be able to enter or leave the craft once it leaves Earth. Therefore they will have to be capable of recycling air, water, and possibly food. The Earth-orbiting Russian Space Station *Mir* is the only spacecraft to date that reuses a key element (water); but it does not recycle its air, and food must be supplied every few months. Spacecraft design must also minimize air leakage and the buildup of harmful gasses.

When humans spend extended time in space, they must cope with psychological challenges associated with living in a radically different environment. For example, astronauts will be living and communicating with the same small group of people for months at a time. Although they can use radio waves to communicate with people on Earth, they will experience time delays as long as 20 minutes as the signals travel through space. These time delays are frustrating and they can be disastrous if the crew needs immediate information in an emergency. The biggest physical challenges facing people in space are exposure to radiation and weightlessness. Even though astronauts are shielded from most radiation in space, they still receive far more than most humans do who stay on Earth. Shielding will have to become even better for humans to travel to such high radiation destinations as Jupiter.

Astronauts also may be subjected to extended periods of weightlessness. Cosmonauts who have spent a year in the weightless environment of space could not walk well when they returned to Earth. They had lost muscle and bone mass and experienced other physical changes. One solution might be a spinning spacecraft or one with onboard centrifuges so that humans can be subjected to gravity-like forces while on a mission. These problems, along with the engineering challenges, must be solved before a human trip to a faraway destination becomes reality.

Suggestions

Students don't have to stick to their assigned roles, but they might discover that the role helps focus their observations.

Ask the "Institute Officials" to review the Site-specific Information on page 31 before the presentations begin so that they will know which sites are being discussed. Decide who will reveal the site locations to the students, and when.

Robotic Guides


NASM

Students studying sites

The *Presentation Checklist* below is designed for you to use in evaluating the student presentations. Students can also use the list to prepare for their presentations.

Site discussed in terms of:

- ☐ Interesting features for study
- ☐ Utilization of available resources
- ☐ Landing versus orbiting recommendations
- ☐ Contending with atmospheric pressure

Length of mission discussed in terms of:

- ☐ Physiological changes
- ☐ Radiation exposure
- ☐ Psychological impact
- ☐ Probability of micrometeoroid impacts
- ☐ Time lag in communications
- ☐ Cost

Site-specific Information

Site A: This Jupiter image taken by *Voyager 2* shows a region west of the Great Red Spot that looks like a disturbed, wave-like pattern. Similar flows are seen to the west of the white oval at the bottom of the photo. The remainder of this equatorial region is characterized by diffuse clouds.

Site B: Triton, Neptune's largest satellite, appears in this *Voyager 2* photo. Its surface is dominated by many roughly circular, polygonal features that are 30–50 km (18–30 mi) across which may be craters. Notice the peculiar double ridge lines that intersect each other. They are 15–20 km (9–12 mi) wide and hundreds of kilometers long. These geologic features and spectroscopic information indicate that Triton is coated with a mixture of ices.

Site C: *Voyager 2* took this picture of Ganymede, Jupiter's largest satellite. The smallest features discernible are 5–6 km (3.1–3.7 mi) across. The band of grooved terrain in the lower left is about 100 km (62 mi) wide. Its left edge shifts 50 km (31 mi) as if it were broken by the linear feature perpendicular to it. This is an example of what happens during an earthquake. This and a similar feature discovered by *Voyager 1* are the first clear examples of strike-slip faulting on any planet other than Earth. Many examples of craters of all ages can be seen in this image. The bright ray craters are the newest. The large, subdued circular markings may be craters from ancient impacts that have been flattened by glacier-like flows.

Site D: This picture of Io, Jupiter's innermost satellite, was taken by *Voyager 1* at a range of 128,500 km (77,100 mi). The width of the picture encompasses about 1,000 km (600 mi). Io is characterized by surface deposits of sulfur compounds, salts, and possibly volcanic sublimates. The dark spot with the irregular radiating pattern near the bottom of the picture may be a volcano with radiating lava flows.

Site E: This composite image of Mars shows numerous impact craters and outflow channels that may have been caused by the release of water to the surface. (Frozen water is present at the poles and in the subsurface of Mars, but no liquid water has been detected on the surface.) The channels cut through a number of craters; this allows us to deduce that the channels are more recent formations than the craters.

Site F: *Voyager 2* produced this close-up view of Miranda, innermost of Uranus's large satellites. The image shows an area about 250 km (150 mi). Two terrain types are visible: a high, rugged terrain on the right and a lower, striated terrain on the left. Craters on the high terrain indicate that it is older than the lower terrain.

Robotic Guides

Several scarps, probably faults, cut through both areas. The impact crater in the lower part of the image is about 25 km (15 mi) across.

Site G: This image shows the Venusian volcano Sapas Mons, which is approximately 400 km (249 mi) across and 1.5 km (0.9 mi) high. The darker flows on the lower right of the volcano may be smoother than the brighter flows near the center. Many of the flows appear to have erupted from the sides of the volcano rather than from its summit. This type of eruption is a feature typical of large volcanoes on Earth, such as those found in Hawaii. The summit area of the volcano has two mesas, which appear dark in the radar image, and groups of pits that are as large as 1 km (0.6 mi) across. The pits may have been formed when the surface collapsed after underground chambers of magma drained. An impact crater with a diameter of 20 km (12 mi), located northeast of the volcano, is partially buried by lava flows.

Site H: This picture of the Moon was taken during the Apollo 17 mission. A portion of the Tsiolkovsky crater dominates this image. This impact crater resulted from a colossal meteoroid. The mound near the center of the image marks the point of impact and is approximately 58 km (35 mi) across. The smooth dark area, the result of lava flows sometime after the meteor's impact, is the crater's present floor. More recent impact craters mark the entire area. The wavy lines are not dry river beds, but rills formed when the surface of the lava pulled apart as it settled in the basin. The wrinkled, convex ridges running perpendicular to the rills in the upper right were probably formed by compression of the lava.

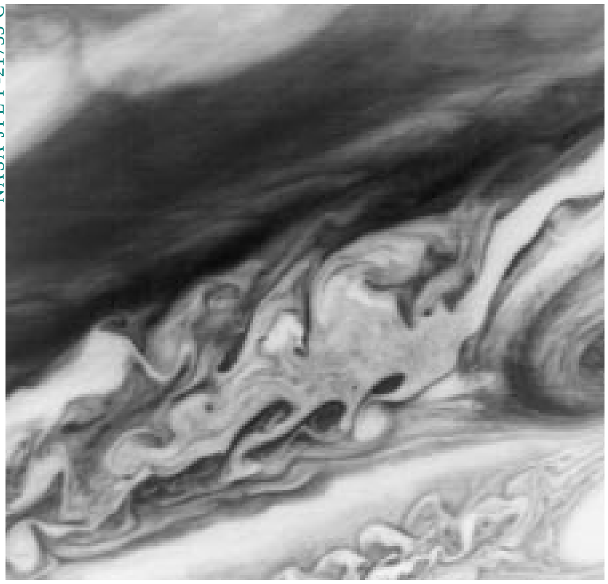
Site Data

	Atmospheric Composition (major constituents)	Atmospheric pressure Earth=1	Surface Composition	Water present	Radius Earth =1	Mass Earth =1	Surface Temp. (°C)	Equitorial surface gravity Earth=1	Most fuel efficient travel time (one way)
	89% hydrogen 11% helium	10^4-10^5	no real surface	No	10.8	318	-183 low -153 high	2.34	2.7 years
	trace methane	trace?	methane ice?	As ice	0.32	0.02	-235	0.25	30.6 years
	none	=0	dirty ice	As ice	0.40	0.03	-138	0.16	2.7 years
	trace sulfur dioxide	trace	sulfur, sulfur dioxide	No	0.27	0.01	-123	0.18	2.7 years
	95% carbon dioxide 1.6% argon 2.7% nitrogen	0.0005 - 0.008	rock and dust	As ice	0.53	0.11	-126 low 27 high	0.38	8.6 months
	none	=0	dirty ice	As ice	0.09	0.00001	-187	0.04	6.1 years
	96% carbon dioxide 3.5% nitrogen	90	rocky	No	0.96	0.82	467	0.88	4.9 months
	none	=0	dirt and rock	No	0.27	0.01	-153 low 107 high	0.17	3 days
	78% nitrogen 21% oxygen	1.00	rocky, liquid water, ice	All forms	1.00	1.00	-89 low 57 high	1.00	—

Student Sheet

SITE A

NASA JPL P-21735 C

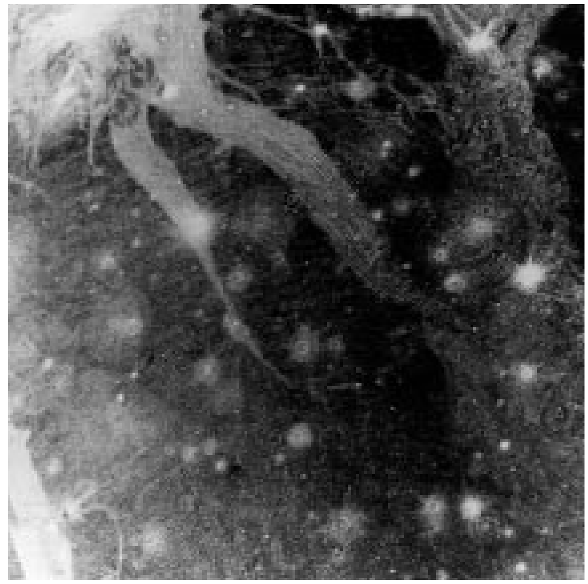


NORTH

Image shows area from 10º North latitude to 34º South latitude; about 56,000 km (35,000 mi). *Note:* surface is not dense enough for a spacecraft to land on.

SITE C

NASA 79-HC-287



NORTH

Image shows features as small as about 5–6 kilometers across. The band of grooved terrain is about 100 km (60 miles) wide.

SITE B

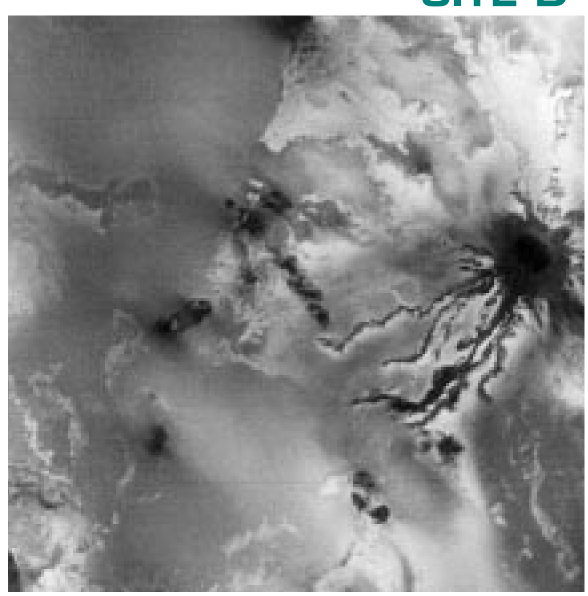
NASA JPL P-34694

NORTH

Image shows double ridge lines measuring from 15–20 km (9–12 mi) wide and hundreds of kilometers long.

SITE D

NASA 79-HC-102



NORTH

Image shows an area about 800 km (480 mi) from top to bottom.

Student Sheet

SITE E

NASA MTM –05152

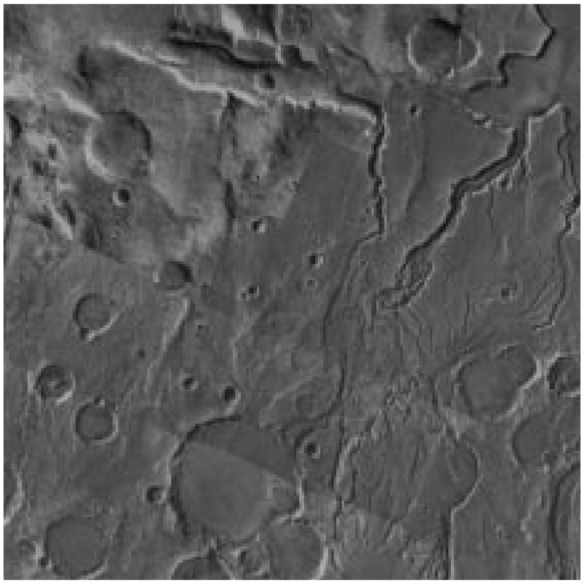


Image shows 5° latitude/longitude; approximately 300 km (180 mi) square.

SITE G

NASA JPL P-38360 MGN51

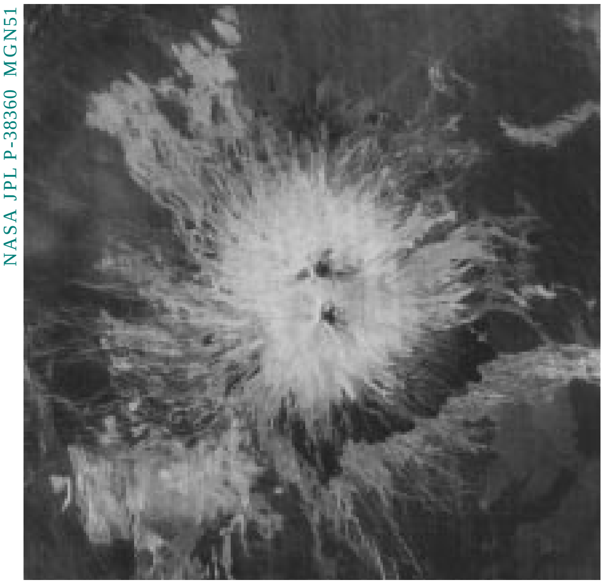


Image shows a crater in the top right quadrant with a diameter of 20 km (12 mi).

SITE F

NASA JPL P-29512 B/W

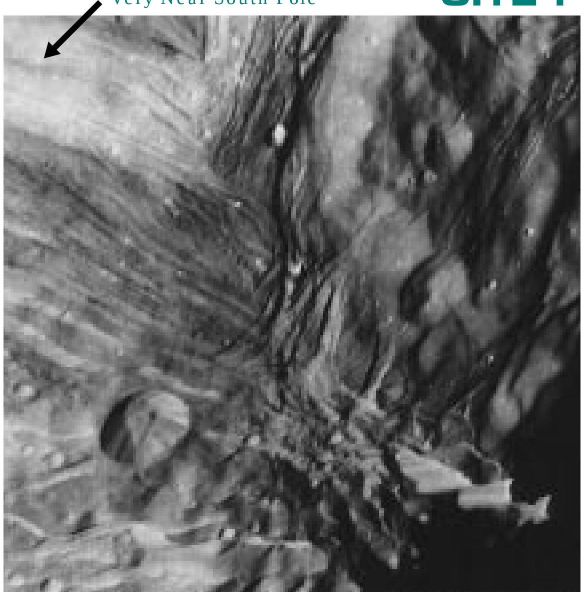


Image shows a crater in the lower half of the photo that is about 25 km (15 mi) across.

SITE H

NASA AS17-139-21302

Image shows mound in center that is approximately 58 km (35 mi) across.

Phoning Home

Communicating Across Space

Goal

To understand the problems of communicating in space

Key Concepts

- Radio waves travel at the speed of light.
- Delays in transmission occur when communicating across the vast distances of space.
- Communication delays produce unique problems.

Overview

If you traveled to Mars in a spacecraft, radio transmissions would be your only way of communicating with Earth. A radio transmission between Mars and Earth takes from four to twenty minutes, depending on how close the planets are to each other. This travel time creates a delay in communication that students will simulate by sending taped messages from "Earth" to "Mars."

Materials

For each group:

Two sets of identical building blocks
Tape recorder
Two blank audio cassettes
Student Sheet on page 38

Preparation

Each group will be divided into two teams. Situate each group of two teams so that each team can build structures out of sight of the other. They can work in the same room if students set up simple table-top cardboard barriers.

Procedure

a. Divide your group into two teams of four students each.
b. Designate one team as Mission Control on "Earth" and the other team as the Field Station on "Mars."
c. Each team proceeds according to the scenario that follows.

Earth–Mission Control	Mars–Field Station
i. Read your scenario on the Student Sheet. ii. Construct a simple habitat using building blocks. Tape-record enough instructions to enable the "Mars" team to build an identical structure. iii. Assign one member as courier to drop off and pick up the cassettes from a predetermined site.	i. Read your scenario on the Student Sheet. ii. Follow the instructions from "Earth" to construct a habitat using building blocks. Tape-record any questions you have. iii. Assign one member as courier to drop off and pick up the cassettes from a predetermined site.

d. Compare the Martian and Earth structures after 15 minutes.

Observe

1. How similar are the structures?
2. What were the most difficult instructions to communicate? What were the simplest?
3. How did communication improve or worsen over time?

Phoning Home

Interpret

4. What part of this activity did you find the most frustrating?
5. What additional tools would make this activity easier?

Apply

6. Imagine living in a Martian colony in the future. What problems could arise because of communication delays?
7. Describe how communication is portrayed in space fiction films.

Glossary

Electromagnetic Radiation—radiation made of electromagnetic waves, including radio waves, x-rays, and visible light. Each type has different characteristics because of its wavelength.

Light—electromagnetic radiation that the human eye can perceive. All electromagnetic radiation, including light, always travels at 300,000 km (186,000 mi) per second.

Radio waves—electromagnetic radiation to which a radio receiver is sensitive. Radio waves have the longest wavelengths of any electromagnetic radiation.

More Ideas

- Try this activity as a competition. Which group had the most similar structures? What set their communication apart?
- Listen in on Space Shuttle conversations using a short wave radio. The NASA Goddard Amateur Radio Club rebroadcasts all air-to-ground communications during Shuttle flights on the following frequencies: 3.860 MHz and 7.185 MHz on the lower single side band, and 14.295 MHz and 21.395 MHz on the upper single side band.
- Study how radios and televisions transmit and receive signals and convert these signals to sound and light.

NASA JPL P19795

Even though radio signals move at the incredibly fast speed of light, they still take time to cross the vast distances of space. As distance increases, allowances must be made for communication delays between spacecraft and Earth.

- By the time you read this, the results of *Galileo's* mission may be known. Research *Galileo's* success and that of numerous other robotic spacecraft that have been sent into space. Look for names such as *Giotto, Luna, Magellan, Mariner, Pioneer, Viking,* and *Voyager.*

In the Film

Experimental designs of Mars rovers are shown as they were tested here on Earth. As you watch the sequence, imagine what it would be like to operate these rovers with the communication delays that occur between the two planets.

On Earth, today's telephone conversations have no time delays no matter how faraway the call. A telephone signal, moving at the speed of light, can travel seven times around Earth in one second, but it would take at least four minutes to reach Mars.

Phoning Home

Try This

Conduct a conversation with a friend who is in another room. Instead of shouting back and forth, write to each other. Ask a third friend to carry the written responses back and forth. What does it feel like to have to deal with the time delay?

What's Going On?

You and your friend are separated by space and time. The delays in your responses probably caused you to change the way you "talked"—you couldn't interrupt each other, you had to finish a thought, you probably wrote complete sentences. As a result, you probably communicated more formally than usual. If you listen to Ham radio conversations, you'll hear the operators talking in similar way because two people can't talk at the same time on a short wave radio.

To the Teacher

If all goes well, structures built on "Mars" should look a lot like structures built on "Earth"—but they may not. Encourage students to focus on the role that communication plays in the building process. For example, if communication became worse, ask them to describe why. Did they become confused and have to ask for more instructions? If so, they may have received more responses than they could sort out. You can point out that this is a dilemma that future space travelers will also have to face.

Students may have never thought of time delays in space communication, especially if they watch a lot of science fiction television or movies. Characters always have a normal two-way conversation even though they are light years apart. In reality, if a spacecraft was three light years from Earth, radio signals would require three years to reach it. Imagine how different most science fiction movies would be if they accurately portrayed communication!

Astronauts on Mars will experience communication delays and difficulties communicating with Earth. Some problems will be easy to handle: If they need verbal instructions clarified with drawings or diagrams, Mission Control could transmit visual information via video or fax. However, the delays mean that astronauts will be able to have normal conversations only with other people on Mars. Delays could also be dangerous if the astronauts are discussing an emergency with Mission Control on Earth.

Link to Space

Astronauts can communicate with Earth only via radio transmissions. Radio waves are similar to light waves and travel at the same speed (300,000 km/sec [186,000 mi/sec]). Time delays occur between sending and receiving messages because radio waves must travel great distances. An astronaut aboard an orbiting Shuttle (typically less than 480 km [300 mi] from Earth) experiences only a slight time delay, much like the delay you experience if you make a phone call to a person halfway around Earth. Astronauts on Mars, however, will have to wait four to 20 minutes for a radio transmission to reach Earth, depending where each planet is in its orbit. And if you were in orbit around Jupiter, a radio signal could take 35–52 minutes to reach Earth.

Astronauts chosen for Mars missions will have to be able to carry out routine operations with minimal assistance. Their onboard computers will be packed with a great deal of information, but they will still need to rely on communications with people on Earth as well.

Suggestions

Discuss potential difficulties before you begin and encourage students to build a simple structure first.

Rewind the tape after each message is delivered; this will help students to find the new message and will avoid mixing new messages with old.

Phoning Home

Students can substitute pencil and paper for the tape recorder. Writing is more time consuming than recording, but it is easier to manage and allows students to include drawings.

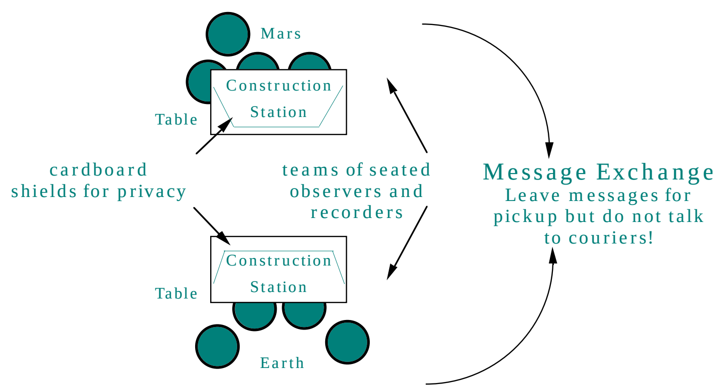
Make sure paired groups are working with identical sets of building blocks.

Couriers must not speak to each other—they should transfer only recorded or written information.

Objects cannot be sent because these would take about nine months to reach Mars in a spacecraft.

While waiting for their first transmission, the "Mars" team can think about the questions they will want the "Earth" team to address. They may also record a message to friends and family describing their experiences, or they can read the information in the *Link to Space* section.

Don't let this activity go on too long. The point is to gain an appreciation for the difficulties inherent in this type of communication, not to build perfect structures.



Student Sheet

Team Descriptions

Field Station on Mars

Congratulations! You're a member of the first team of humans to land on Mars. Most of the mission is going remarkably well, but you've had one potential problem: Some of the building materials for one of the smaller habitats were damaged during a rough landing. You now need to build a livable structure from the materials you have left. You'll need to radio Earth requesting new instructions from Mission Control. Remember: You cannot have a two-way conversation with anyone on Earth because your messages will need at least four minutes to reach Earth.

Mission Control on Earth

Congratulations! You're a member of the first team to send people to Mars. Most of the mission is going remarkably well, but you've just received a message from the field station crew about a potential problem: Some of the building materials for one of the smaller habitats were damaged during a rough landing. You need to send instructions to the Martian crew for building a livable structure from the materials they have left. Remember: You cannot have a two-way conversation with the crew because your messages will need at least four minutes to reach Mars.

Sending Signals

Programming Robots

Goal
To gain an appreciation for how robots are programmed to perform specific tasks

Key Concepts
- Complex tasks are composed of a number of simple tasks.
- Robots are designed to perform specific tasks.
- Robots perform tasks based on input stored in their memory or sent by human programmers.

Overview
Robots have been a part of the space program from its beginning. As space explorers they never need companionship, life support, or to return home. They do, however, present enormous communication challenges. They must be intricately programmed to do such things as walk or recognize objects. Robot operators either send this information directly to the robot or preprogram its instructions before it is sent on its mission. In this activity, students play the role of either programmer or robot to get a sense of how instructions for a simple task might be sent to a robotic spacecraft.

Materials
For each pair of students:
One pair of mittens
Blindfold

Preparation
- Allow students to spend 15 to 20 minutes following the *Procedure*, then choose one pair of students to demonstrate a new task for the class.
- Determine this task ahead of time (see *Suggestions* in teacher section) and keep it secret from the student "robot."

Procedure
a. Work with a partner to decide who will be the robot and who will be the programmer.
b. Devise a list of simple commands such as the follow ing and decide how each will be performed: *Step, Reach, Grasp, Stop, Right, Left, Up, Down, Backward, Forward*.
c. Practice giving and receiving signals. (If the room is noisy, you may need to say your robot partner's name before each command. For example, "Bobby, move forward one step," "Bobby raise right arm six inches," etc.)
d. Blindfold your robot partner and put mittens on its hands.
e. *Programmer:* Plan a simple task for your robot partner such as opening a book and give the necessary commands so that your robot partner can perform the task. Don't tell your partner what the task is.
Robot: Follow the commands as precisely as you can, even if they do not seem to make sense. Do not yield to the temptation to fill in missing commands.
f. Choose one pair of students to demonstrate a task for the class. Choose a new task for the robot partner, who should not know what task it will be performing.

Sending Signals

Observe

1. What tasks is the robot partner able to do easily?
2. What tasks seem difficult?
3. Did anything surprise you in the way the robot partner performed?

Interpret

4. Why does the robot partner wear a blindfold and mittens?
5. What makes some tasks more difficult than others for the robot?
6. Why are only simple commands sent to the robot?

Apply

7. List a task you think you could perform better than a robot.
8. List a task you think a robot could perform better than you and briefly explain why you think so.
9. If the robot could send you information, what kinds of information would be most useful?
10. You communicated with your robot partner using verbal commands. How might you communicate with it if it were traveling through space?

Engineers are testing mini-robots such as these for interplanetary travel. They are relatively cheap to send and they don't get homesick. A fleet of tiny robots can cover more ground than a single craft, and if one fails, others can continue working.

This Russian Mars Rover maneuvers the rough terrain of Death Valley, California, by following detailed instructions programmed into its onboard computer. More elaborate versions of such a robot might help build a base on Mars.

More Ideas

- Write a simple program for your "robot" by making a list of commands. As before, keep each step simple and try not to leave out any steps. Read the program to a friend who has agreed to play "robot." Does the "robot" accomplish its task? How might you change the program to make it work?
- Chalk a maze on the floor and guide a "robot" volunteer through it using programming techniques.
- Devise a simple experiment for a "robot" to do. For instance fill three containers, one with sand, another with gravel, and another with marbles. The "robot" could send you simple information on each so that you could determine what was in each container without actually seeing it.

In the Film

The film shows numerous examples of robots—including mini-robots, the Russian Mars Rover, and robotic spacecraft such as *Galileo* and *Magellan*.

Sending Signals

To the Teacher

Tasks that are simple for most humans to do, such as opening a book, or replacing a flashlight battery, are quite difficult for most robots because such simple tasks are actually composed of numerous individual steps. For example, when you sign your name, you pick up a pen, put it on paper, and move it in an intricate series of directions. By sending simple commands to the robot, you become more aware of how complex tasks are made up of many simple steps.

Although sophisticated robots can be programmed to make choices and evaluate their environment, most robots require specific commands (stored in their memory or sent from a programmer) before performing a task. In contrast, humans are so used to making the many decisions involved in simple tasks that it's difficult for them to act like robots. Reducing stimuli with blindfolds and mittens helps the robot partner control the urge to fill gaps in the instructions.

Students should be able to list numerous tasks that they can perform better than a robot. Tasks that require pattern recognition (such as distinguishing between a dog and a cat) or fine motor coordination (such as brushing a child's hair without hurting) are typically much easier for a human to perform than a robot. Tasks that require endless repetition, a large amount of force, precision, or exposure to a hazardous environment may be more suitable for a robot than a human. (See "So You Want to be a Robot?" right, for examples.)

In order to design and program an effective robot, engineers and scientists have to decide exactly what kind of information they will want from the robot. Encourage students to think about a place they would like a robot to explore and the kinds of information that a robot would be able to collect. For example, robots can carry instruments that take pictures, measure chemical composition, record temperatures, and perform experiments.

Link to Space

Engineers program robotic computers to function as independently as possible, but communication between robotic space explorers and Earth is still necessary. Such communication is sent as radio signals. Because of the vast distances between Earth and the spacecraft, delays occur in receiving messages. These delays are expected and planned for and usually offer no problems unless the spacecraft is experiencing difficulties. Fortunately, robots don't mind waiting.

Suggestions

Ideas for tasks for the student-robot to perform include using a small shovel to scoop gravel from one container to another, walking across the room having to step over or around something, stacking three or four blocks, turning a light switch on and off, walking to a chair and sitting on it, writing something on the chalkboard, and moving a small object from one desk to another.

So You Want to Be a Robot?

Have your students imagine that they are robots, then read this list of jobs that robots do. How do they react?

- Descending into an erupting volcano
- Exploring the crushing depths of ocean trenches
- Swimming beneath Antarctic ice
- Mopping up radiation in a nuclear power plant
- Retrieving a bomb from the bottom of the sea
- Entering a building where armed terrorists are holding hostages
- Filling and capping soft-drink bottles all day, every day
- Cleaning sewers

Spinning Spacecraft

Simulating Gravity

Goal

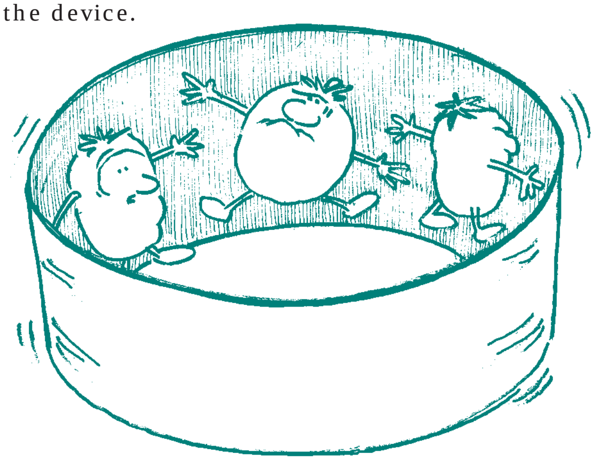
To understand that inertial forces on rotating spacecraft can simulate Earth's gravitational force

Key Concepts

- The acceleration and inertial force generated in a rotating spacecraft depends on the spacecraft's radius and rotation rate.
- Inertial forces can simulate gravitational forces.
- Earth's gravitational force accelerates objects at a constant rate.

Overview

An astronaut's body adapts to the weightless environment of space. For example, fluids shift within the body and muscles lose mass and strength. These adaptations, although suitable while living in space, can cause problems when an astronaut returns to Earth. One way to avoid many of these problems is to simulate gravitational forces by spinning the spacecraft. In this activity, students build a small spinning device to determine how radius and rotation rate affect the acceleration of objects in the device.



This amusement park ride is a centrifuge. The riders feel pushed to the outside with more force than their weight, which makes them "stick" to the walls. Future space explorers may use an onboard centrifuge to help counteract the effects of weightlessness by creating gravity-like forces.

Materials

For each group:

Salad spinner with turning handle (*not* pull cord)
Four dice of assorted sizes
Empty can (about 8 cm or 3 in high)
Corrugated cardboard (about 10 x 30 cm or 4 x 12 in)
Hot glue gun and glue
Tape

NASM

Apparatus unassembled. Holes punched in small lid aid visibility.

NASM

Apparatus assembled. Turning knob on top will make cage spin.

Preparation

- Strip the top layer from the corrugated cardboard to expose the ridges. Line the inside of the can with the cardboard, positioning the ridges so that they are vertical when the can is upright.
- Glue the bottom of the can to the center of the under side of the salad-spinner lid, matching their center points exactly.

Spinning Spacecraft

Procedure

a. Place the dice in the basket.
b. Tape the basket to the lid so that it can still spin freely.
c. Hold the salad spinner on its side so that the basket will spin vertically like a Ferris wheel.
d. Turn the handle slowly and observe what happens. Record your observations.
e. Slowly increase the spin rate. Record your observations.
f. Remove the basket and put the dice inside the can. Repeat *steps c–e*.

If a spacecraft could rotate on a tether, such as in this computer model, it might provide the gravity-like forces needed to maintain muscles and bones in space.

Questions

1. What did you notice as you slowly turned the handle?
2. What did you notice as you increased the spin rate?
3. Which setup—inside the can or the basket—requires a slower spin rate for the dice to ride all the way around without falling?
4. What causes the dice to "cling" to the perimeter while the device is spun?
5. What affects the force acting upon the revolving dice?
6. How does a washing machine apply the principle you investigated in this activity?
7. Anytime you've been in a turning vehicle or a rotating carnival ride, you've felt inertial forces. Describe your experience.
8. List one advantage and one disadvantage of a spinning spacecraft.

Problems

9. Place the dice in the basket again, and increase the spin rate until you can see or hear that the dice are "sticking" to the edge of the basket. (The spinning dice should sound quieter and more rhythmic.) Slow the spin just enough so that the dice do not fall.
   a. Determine the number of revolutions per second of the basket. (Count the revolutions for 30–60 seconds and divide by the number of seconds. Remember to start counting at zero. If you count handle revolutions instead of basket revolutions, you will need to determine the gear ratio of the handle to the basket.)
   b. Measure the basket's inside radius in meters.
   c. Calculate the distance traveled. It equals $2 \pi r$.
   d. Now that you know the revolution rate and the distance traveled, calculate the perimeter speed.
   $$v = d \times \frac{\text{rev}}{\text{sec}}$$
   e. Calculate the centripetal acceleration of the basket knowing that $a = \frac{v^2}{r}$
10. Place the dice inside the can and repeat *problem 9*.
11. Compare centripetal accelerations for the basket and can.
12. Earth's gravitational acceleration is 9.8 m/s^2. If a rotating spacecraft needed to match Earth's acceleration at its perimeter, what radius would the space craft need to be if it were turning once each minute?
13. Imagine a spacecraft connected by a 20 km tether to a counterweight that matched the craft in weight. What revolution rate would give the spacecraft an acceleration of 9.8 m/s^2?

Spinning Spacecraft

Glossary

Inertial Force—fictitious force felt by a person in an accelerating frame of reference. Coriolis and centrifugal forces are examples of inertial forces. If you were riding in the car in *Figure 1* you would feel as though you were being pushed toward *A*. In fact there is no real force pushing you in this way. You could test this by falling out of the car. Instead of falling toward *A*, you would move in a straight line toward *B* (until you hit the ground). The feeling of being pushed toward *A* is explained thus: Your moving body "wants" to go straight toward *B* (due to inertia), but the inside of the turning car keeps "running into" you.

Centripetal Force—force directed toward the center of the curvature of a path and acts upon an moving object to keep it on the path.

To test the idea of tethering a spacecraft, a satellite was deployed from the Space Shuttle while attached to a thin tether more than 19 km (12 miles) long.

Student watching dice while spinning apparatus

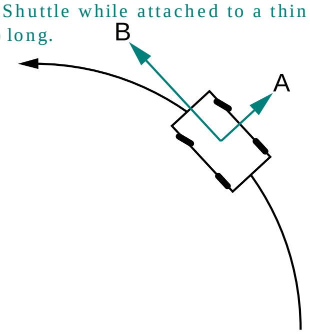


Figure 1. A turning car with force diagrammed

More Ideas

- Watch segments of the film *2001: A Space Odyssey* that show scenes of life aboard a rotating spacecraft.
- Visit an amusement park and look for rides that generate inertial forces.

In the Film

Students see several ideas of how spacecraft could be designed to provide gravity-like forces to maintain astronauts' health during long flights—a fictitious example from *2001: A Space Odyssey*, plus an animated tethered craft that is more realistic (see photo, page 43).

To the Teacher

When the salad-spinner basket rotates slowly, dice may "climb" the walls a little way before falling back to the bottom of the basket. As the speed of rotation increases, dice will ride further and further up the sides until at last they ride completely around. When this happens, the outward inertial force is greater than the gravitational force on the dice.

Dice in the basket will begin to ride around the walls at a slower spin rate than will dice in the can becasethe basket has a larger radius than the can and the outward inertial force therefore is greater. Outward inertial force also increases with the speed of rotation. In addition, the speed of a rotating object is much greater toward its perimeter. Students who have played "Crack the Whip" should be familiar with this concept.

Spinning Spacecraft

Technically, there is no force pushing the dice outward. According to Newton's first law, objects remain in constant, straight-line motion until acted upon by a force. If an object is moving in a straight line inside a turning object, such as a spinning spacecraft, its tendency will be to continue in that straight line (due to its inertia) but it will run into the sides of the turning craft as though it were being pushed. The inside walls of the basket and can are forcing the dice to follow a circular path. The presence of inertial forces (in this activity, the centrifugal force), indicates that an object (the die) is in an accelerating frame of reference (the spinning basket or can).

Washing machines apply Newton's first law during their spin cycles: As they spin, washing machines hold the clothes while the water moves in a straight line right through the holes in the spinning basket. Remind the students that they have also felt inertial forces while riding in a car that is turning a corner and while turning upside-down loops on a roller coaster.

Future humans living aboard spinning spacecraft will have most of the benefits of living in a gravity-like environment and will avoid many of the negative physiological consequences associated with weightlessness. Drawbacks to living in a spinning spacecraft include losing the benefits associated with weightless environments, having to deal with other inertial forces such as the Coriolis effect, and having to deal with noticeable variations in the inertial force within the spacecraft. For example, the strength of the force increases from zero at the center of rotation to maximum force at the perimeter of the craft.

Link to Space

As humans plan expeditions to Mars (a one-way trip takes about nine months), scientists are concerned that extended living in a weightless environment might drastically impair astronauts' ability to function in gravitational environments. The physiologic changes include loss of muscle and bone, strength and mass. Possible solutions include building a rotating spacecraft or rotating the craft from a tether as described in the film. This activity simulates placing a centrifuge on board to generate inertial forces with varying acceleration rates depending on its rotation rate. It could provide various gravitational forces for experimental and control setups and therapy for astronauts to counter the effects of weightlessness.

Students may realize that in this Earth-bound activity, a die's weight will cause it to experience less force at the top of its revolution and more force at the bottom. This discrepancy would not occur in a weightless environment.

Suggestions

Allow students to investigate dice combinations, radius size and spin rates by playing with the device.

The activity can be done both qualitatively (conceptually) by answering the questions, or quantitatively (mathematically) by completing the calculations on page 43.

Because different masses should give the same result, you can use dice that weight between one to 35 grams. Larger objects will put too much strain on the simple mechanism and add to experimental error.

You can substitute other square objects, but do not use marbles or balls—their rolling inertia will result in *huge* errors for this experiment.

Do not purchase salad spinners that use a pull cord. These cannot maintain a spin; as the cord is pulled to its limit, it rewinds and acts like a brake.

Corrugated paper, such as that used for packaging light bulbs, can be substituted for the corrugated cardboard. Glue guns are sold in craft and hardware stores; these dispense hot glue, which was the most successful glue we tried.

Spinning Spacecraft

Answers to problems:

Note: Students must heed directions in *problem 9* to achieve accurate data. A die requires a faster rotation rate to complete its first revolution than it does to continue revolving. Suggest that the students practice slowing the spinning rate before they begin counting revolutions.

The calculations use figures obtained while field testing the devices. Your students' figures and answers will vary depending on the size of the salad spinner and the can. *Note:* the weight of the dice will not affect your data.

9. a. Revolutions per second:

$$\frac{14 \text{ cranks}}{20 \text{ sec}} \times \frac{4.25 \text{ rev}}{\text{crank}} = \frac{3.0 \text{ rev}}{\text{sec}}$$

b. Basket radius = 0.098 m

c. Perimeter speed:

$$d = 2\pi r = 0.616 \text{ m}$$

$$v = \frac{d}{t} \text{ or } v = d \times \frac{\text{rev}}{\text{sec}}$$

$$= 0.616 \times 3.0$$

$$= 1.8 \text{ m/s}$$

d. Centripetal acceleration:

$$a = \frac{v^2}{r}$$

$$= 33 \text{ m/s}^2$$

a. Revolutions per second:

$$\frac{19 \text{ cranks}}{20 \text{ sec}} \times \frac{4.25 \text{ rev}}{\text{crank}} = \frac{4.0 \text{ rev}}{\text{sec}}$$

b. Can radius = 0.036 m

c. Perimeter speed:

$$d = 2\pi r = 0.226 \text{ m}$$

$$v = \frac{d}{t} \text{ or } v = d \times \frac{\text{rev}}{\text{sec}}$$

$$= 0.226 \times 4.0$$

$$= 0.90 \text{ m/s}$$

d. Centripetal acceleration:

$$a = \frac{v^2}{r}$$

$$= 23 \text{ m/s}^2$$

11. Allow for large experimental error because the device and measuring instruments used in this activity are not precise. For example, a single crank turn can change the results by more than 10 percent. Ideally, the acceleration required for the dice to overcome gravity in a vertical position should be just over 9.8 m/s^2.

12. Knowing that

$$v = \frac{d}{t} \quad \text{and} \quad d = 2\pi r$$

then substituting for d

$$v = \frac{2\pi r}{t}$$

knowing that

$$a = \frac{v^2}{r}$$

then substituting for v

$$a = \left(\frac{2\pi r}{t}\right)^2 \times \frac{1}{r}$$

substituting values

$$a = 9.8 \text{ m/s}^2 \text{ and } t = 60 \text{ s}$$

$$r = 890 \text{ m}$$

13. Substituting values

$$r = 10{,}000 \text{ m}$$

$$a = 9.8 \text{ m/s}^2$$

solving for velocity

$$a = \frac{v^2}{r}$$

$$v = 313 \text{ m/s}$$

solving for distance

$$d = 2\pi$$

$$= 62{,}800 \text{ m}$$

solving for period

$$\frac{1}{t} = \frac{v}{d} = \frac{313}{62{,}800}$$

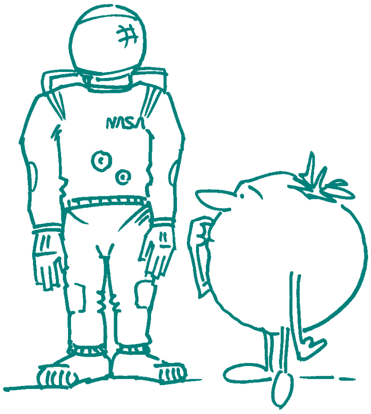
$$= 200 \text{ s/rev} = 3.3 \text{ min/rev}$$

Suiting Up for Space

Goal
To match the parts of a space suit with their functions

Key Concepts
- The environment of space cannot support human life.
- A space suit functions like a miniature spacecraft to enable an astronaut to work outside the spacecraft.
- Closely observing a space suit can lead to a better understanding of its functions.

Overview
People wear body coverings to help them live and work in different environments—including space. There, astronauts need suits to protect them from hazardous radiation and to deal with a lack of oxygen. In this activity, students describe the space environment and identify the functions performed by various parts of a space suit.



Materials
Space suit for observation (actual or photograph)

Preparation
- Collect pictures of space suits or arrange a field trip to a facility where you can study an actual space suit.
- Design a chart for your observations titled, *Linking Space and Space Suits*. Divide the paper into three vertical columns and label each with the headings shown in Table 1a.

Procedure
a. Study a space suit and discuss the questions given to you from your teacher.

b. How would you describe the environment of space? Write your descriptions in the first column of your record sheet.

What Space is Like (Characteristics)	Parts of a Space Suit (Structures)	What a Space Suit Does (Functions)
weightlessness	air tanks	supplies air
no air	backpack with jets	absorbs carbon dioxide
	line to spacecraft	prevents astronaut from floating away

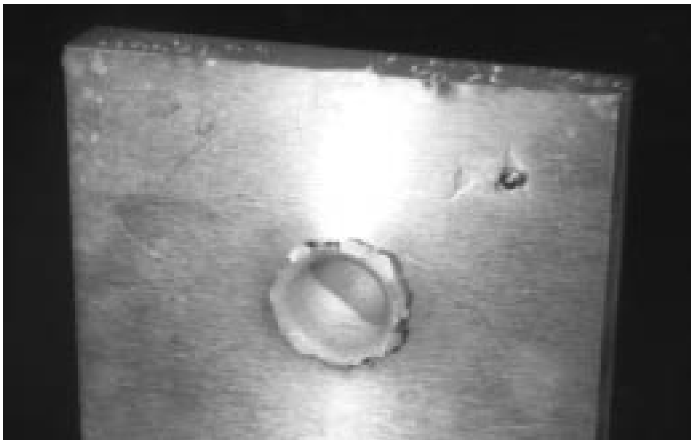
Suiting Up for Space

c. List the different parts of a space suit in the second column; in the third column, describe what each part does.
d. Draw lines to match items in each column with items in the other two columns (Table 1a).
e. Discuss the questions and your charts with other groups. Add any new information that you gain from the discussion to your charts and make any new connections you discover.

Questions

What do you notice about the space suit? What do you wonder about? Think about where an astronaut wears the suit—what is the space environment like? People who designed the first space suits borrowed ideas from deep-sea diving suits. Why would they do this? What are some similarities between the environment of space and that of the ocean? How are the two suits—space and diving—similar?

How thick is the space suit? How many layers do you see? what are the layers for? How does a space suit protect an astronaut from micrometeoroids and other objects in space? How does it protect an astronaut from the intense heat and cold of space? Would an astronaut overheat while wearing a space suit?



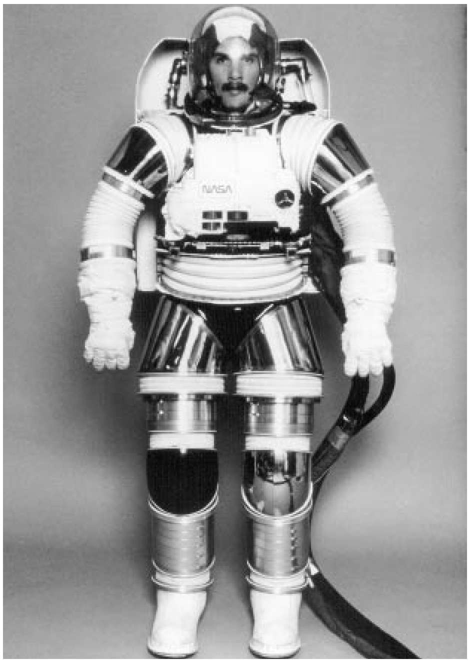
NASM

This block of aluminum shows the damage caused by a BB-sized object moving about 6,000 m/s (13,400 mph), which is slower than orbiting objects move. (Crater shown actual size.)

Find the Life Support System. Where does the astronaut's oxygen come from? Where does the carbon dioxide go? How does a space suit maintain pressure around an astronaut's body? Why is this important? Where would an astronaut find a small snack and drinking water?

How heavy do you think the space suit is? Does its weight matter in space? What prevents an astronaut from drifting away when working outside the spacecraft? What features of the space suit help the astronaut control movement in space? Why is movement in space different from movement on Earth?

What kinds of work do astronauts perform while wearing space suits? What tools are a part of the suit? An astronaut can work in a space suit for seven to eight hours. What might limit that time? Can astronauts move arms and legs easily in a space suit? Find the parts of a space suit that allow astronauts to communicate.



NASA 87-HC-154

The next generation of space suits will probably be rigid. Unlike soft suits, hard space suits can maintain standard sea-level pressure.

Suiting Up for Space

Glossary

Extravehicular Activity (EVA)—activity performed by an astronaut outside of a spacecraft, in space, or on the Moon.

Life Support System—backpack unit that connects to a space suit to regulate temperature, maintain air pressure, provide oxygen, and absorb carbon dioxide.

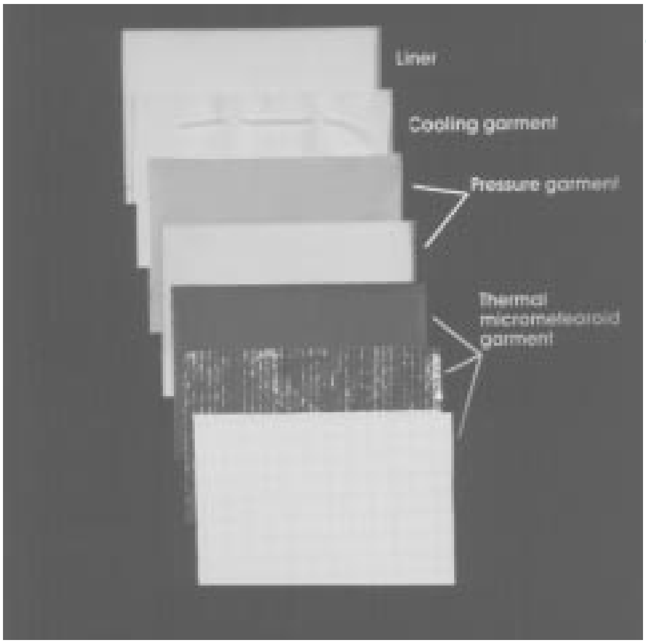
Manned Maneuvering Unit (MMU)—fits over the Life Support System and enables the wearer to move through space by operating gas thrusters on the unit.

In the Film

Watch the footage of astronauts servicing the Hubble Space Telescope, and observe how a space suit protects and also encumbers an astronaut.

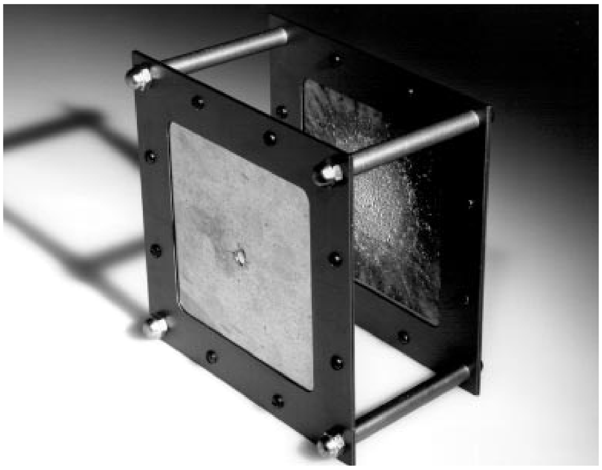
NASA 90-HC-301

Bruce McCandless has put on the thermal undergarment that he wears beneath his space suit. Note small holes where cooling tubes are interwoven into the garment.



NASM

Each layer of a space suit has a purpose. Many thin layers also make the suit more resistant too micrometeoroid penetration than a single, thick layer would be.



NASM

Micrometeoroids often impact with explosion-like force. Current research shows that two widely-spaced, thin layers resist penetration much better than a single thick layer.

Suiting Up for Space

Try This

Take apart a toy or other object that has simple interlocking pieces. Try putting it back together while wearing ski gloves, garden gloves, or large rubber work gloves. How do the gloves affect your task? How do your hands feel as you work?

What's Going On?

While outside the spacecraft, astronauts must wear gloves as part of their space suit. With these bulky gloves on, astronauts cannot do many simple tasks that we do every day. Their hands also tire easily while working in the gloves. This hand fatigue is a major problem for astronauts who work outside a spacecraft.

To the Teacher

Discussion questions will help students focus on details when looking at an object as unfamiliar and as complicated as a space suit. They can discuss their findings informally within their group and then develop their ideas in the class discussion.

Before students begin identifying structures and functions of space suits, encourage them to list as many characteristics about space as they can recall. Then, if they have difficulty recognizing the structures of a space suit and their functions, remind them to think of how a space suit might be designed to handle various characteristics of space. Table 1b provides information you might want to share with your students.

The space environment cannot sustain human life for several important reasons: It is a vacuum; it can produce extreme temperature fluctuations; and it is traversed by radiation and by objects such as micrometeoroids. Space suits are designed to allow astronauts to work in this environment. The suits reflect solar energy to prevent astronauts from overheating when they are working in the sun, and they insulate astronauts from extreme cold when they are working in the shadow of Earth or of the spacecraft.

Designers of early space suits learned from people who had designed deep-sea diving suits. Both environments are inhospitable to humans because of their pressure (too much undersea and too little in space) temperature (too cold underwater and extreme ranges in space) and also because of humans' inability to breathe in either environment. Pressurized suits are designed to maintain livable pressures and temperatures as well as to provide oxygen for breathing. Even today, suits for both environments look similar with their bulky structure and rigid helmets.

In the beginning of the U.S. space program, astronauts wore their suits for the duration of the flight. The Shuttle crew members wear space suits only when they are working outside the spacecraft. While they are inside the controlled environment of the cabin, they wear comfortable shirts and shorts or slacks.

Space suit design has also changed through the years. For example, the Mercury suits had three layers of protection, Gemini suits had 18–22 layers , and Apollo suits had up to 25. The Shuttle suit has 11 layers and a fiberglass shell in the upper torso.

Suiting Up for Space

The following descriptions examine the Space Shuttle suit from the inside out. Although your students may be looking at other space suits, they will find similarities. Closest to an astronaut's body is a urine collector that is a modified pair of underwear. The next layer is a nylon garment that looks like long underwear and is almost as comfortable. Cold water flows through plastic tubing embedded in this layer. The water cools the astronaut by absorbing body heat. This water is then cooled again when it circulates through the backpack. After putting on these two elements, the astronaut puts on the two main parts of the suit—the upper and lower torso. These two parts fasten by interlocking pressure-sealed steel rings.

The inner layer of the main suit is a pressure bladder that acts like a car tire, sealing in air pressure while restraining expansion. Next is a restraining layer that gives the pressure bladder additional support and shape. These two layers are enclosed by multiple layers that provide thermal insulation and protection from tears and punctures. Beneath the upper torso layers, a hard, armor-like shell provides a rigid surface for mounting larger equipment.

What Space is Like (Characteristics)	Parts of a Space Suit (Structures)	What a Space Suit Does (Functions)
	backpack with jets or thrusters	moves astronaut around
weightlessness	line to spacecraft	prevents astronaut from floating away
very hot	cool water in tubes inside suit	cools astronaut
		insulates astronaut from very cold or hot temps.
freezing cold		
particles in space and other debris	many layers	protects astronauts from debris in space
		supplies air to astronaut
no air to breathe	air tanks	absorbs carbon dioxide
no air pressure (vacuum)	layer that holds pressure	maintains air pressure around astronaut
sound doesn't carry	radio	lets astronauts talk with others
	flexible joints	allows astronaut to move arms and legs easily

Table 1b. Linking Space and Space Suits.

The astronaut's head is protected by a fabric cap and a plastic helmet. The helmet contains two visors—a clear one that protects against the vacuum of space and micrometeoroids, and a gold-coated one to filter the sunlight. Interlocking pressure-sealed steel rings join the helmet to the neck of the suit.

The astronaut's outer gloves are also attached with interlocking rings. Astronauts wear "comfort gloves" inside the multiple-layered outer gloves.

The Life Support System backpack unit provides all the elements needed to keep an astronaut alive. It provides oxygen from a pressurized supply and contains substances that absorb exhaled carbon dioxide. Astronauts wearing space suits breathe pure oxygen because their suits maintain a lower air pressure than found in the Shuttle or on Earth's surface. (The Shuttle cabin maintains a standard sea-level pressure of 101 kPa or 1 atm or 14.7 psi; the airtight suits maintain a pressure of 29.6 kPa or 0.3 atm or 4.3 psi.) If space suits were inflated to normal sea-level pressure, they would act like a rigid, inflexible balloon.

Refreshments are attached within the suit: A drink bag is attached to the suit near the neck ring and a plastic straw extends into the helmet; a snack of fruit, grains, and nuts—wrapped in edible rice paper—is attached where the astronaut can bite it easily.

How much does all this gear weigh? An average Space Shuttle extravehicular activity (EVA) suit weighs approximately 112 kg (247 lb) on Earth—but nothing at all in space.

Outside the craft, astronauts would drift away unless they were either tethered to the craft or wearing an MMU (Manned Maneuvering Unit) backpack. The MMU allows an astronaut to maneuver with hand-operated gas thrusters that propel the astronaut in the opposite direction.

Suiting Up for Space

Astronauts perform a variety of activities outside the spacecraft, from building experimental structures to capturing and repairing satellites. Although they can remain outside the Shuttle for up to eight hours, astronauts rarely stay outside this long. They might use up their oxygen faster than expected, or they might tire from maneuvering in the bulky space suit. Hands become particularly fatigued, as demonstrated by the *Try This* activity on page 50. Astronauts' gloves are carefully designed to allow as much hand movement as possible while still providing the necessary protection. Rubberized fingertips aid in handling tools and objects.

A space-walking astronaut can listen and talk to other astronauts on board the craft using earphones and a microphone contained in the fabric cap. Radio communications are contained in the Life Support System backpack.

Link to Space

In the beginning of the space program each space suit was custom-fitted to a particular astronaut. Today the astronaut corps is much larger, so custom-fitting suits would be prohibitively expensive. Instead, technicians assemble suits from components made to fit assorted sizes.

Suggestions

You may want to assign one set of questions to each student group. Groups can then report their findings to the rest of the class.

The National Air and Space Museum does not display a Shuttle suit because the suits are all still in use. Astronauts wear old suits during underwater training.

Refer to Table 1b if students are having difficulty identifying structures and functions of space suits.

You Can Take it With You

In Fact, You Have to

Goal
To determine how much fluid a person drinks each day

Key Concepts
- Water requirements must be determined for space missions.
- Spacecraft will have to carry all the water a crew needs.
- Waste water can be purified by recycling processes.

Overview
Astronauts have a limited amount of water available because of space and weight limitations for water storage aboard spacecraft. In this activity, students carry a day's water supply and record how much they use. Then they compare their consumption with that of astronauts in space.

Materials
Plastic drink bottle with lid, one per student
Scale

Procedure
a. Fill a clean, plastic bottle with drinking water.
b. Carry this bottle with you for 24 hours.
c. If you want a drink of water, take it from the bottle.
d. If you drink another liquid, pour out the same amount of water. For example, if you drink a 12-ounce bottle of juice, you must pour out 12 ounces (355 ml) of water from your bottle. You can use the empty juice bottle to measure the correct amount.
e. Refill the bottle only when it is empty. Be sure to keep track of how many times you refill it.
f. At the end of 24 hours, measure the amount of water left in the bottle and calculate how much fluid you drank.

Observe
1. How much fluid did you drink in 24 hours?
2. When did you drink the most?
3. List two ways you use water without actually drinking it.

How are you saving weight on your spacecraft?

We're taking dehydrated water.

You Can Take it With You

Interpret

4. List two things that happen to the water you drink.
5. Why would astronauts need to conserve water during a space mission?
6. Why might they need to recycle water on a long trip?

Apply

7. Could you live within these limits? Space station astronauts will use a total of 6.8 liters (about 1.75 gallons) of water per day for personal hygiene. [4.1 liters (about one gallon) for washing hands and face, and 2.7 liters (about 0.75 gallons) for a shower.]
8. Imagine seven astronauts traveling to Mars on a three-year mission. Why wouldn't they be able to take all of their drinking water?
9. What water-related recreational activities would you miss if you went into space for an extended period of time?

NASA 82-HC-540

The "needle" on this water rehydration unit delivers water directly into the container to prepare the dehydrated food for eating. Notice the food tray in the upper right.

Problems

10. How much does one liter of water weigh?
11. How much water did your entire class consume in one day? What was the average amount?
12. Suppose you had to stockpile a year's worth of drinking water for one person in your class, based on the average amount of water consumed per person: How much would the supply of water weigh?

Glossary

Conservation—using a resource carefully instead of wasting it.

Recycling—reusing a resource. For example, waste water can be recycled into drinking water by removing contaminants. The method of recycling depends on what is being recycled.

More Ideas

- Keep track of all the water you use in a day, including what you use for food preparation, bathing, and flushing the toilet. Compare the amount of water you use in a day to what astronauts might be allowed to use aboard a space station. (See Table 1 on page 56.)
- Compare Earth's water cycle to the water cycle aboard a spacecraft. Include the processes of evaporation, transpiration, respiration, condensation, and precipitation.

In the Film

The film shows a technician tending plants in a hydroponic facility at the Kennedy Space Center in Florida. Here scientists test techniques for maintaining a closed system by growing plants in this room, which can be sealed. During the test period, all elements in this room are reused, as they would be in extended space travel.

You Can Take it With You

To the Teacher

Although this activity focuses on drinking water, tell students that they need to record any fluid they consume. All beverages—including milk, soft drinks, and juice—are water-based. The implications this has for space travel increase when you remind students that Earth is the only place we know of that has liquid water on its surface!

The students' water consumption may range from about 1,000 ml (34 ounces) to 1,700 ml (58 ounces), depending on their age, size, and activity. They will probably drink the most water during meals, following physical activity, or after a partial fast (first thing in the morning or just after school).

Students should be able to list many ways they use water, including hygiene, recreation, cooking, cleaning, and gardening. Of the water we drink, most is excreted as urine, respired through the lungs, or perspired through the skin. A very small percentage becomes tears, saliva, or is incorporated into the body as cell growth. Table 1 on page 56 gives a more detailed breakdown.

Water conservation is critical on space flights. Water—even in small amounts—is heavy. For this reason, spacecraft can carry only a small supply. That amount is conserved and recycled. For example, astronauts are allowed very little water for personal hygiene. Sinks are designed to use very little water, and the toilets don't use water at all. Some spacecraft, such as the Space Shuttle, have no shower.

Even though astronauts use very little water per day—on average, 23.67 liters (6.25 gal)—a three-year supply for seven astronauts would weigh 180,933 kg (398,890 lb). Spacecraft can't carry that amount of water, so intensive water conservation and recycling will be needed on a space flight to Mars.

Students can calculate the average volume of drinking water for their class by adding the fluid consumed by all the students who participated in the activity, then dividing the total by the number of those students. If a student drank 1.85 liters (0.49 gal) in 24 hours, that adds up to 673.4 liters (177.9 gal) in one year, according to the following calculations:

1.85 liter/day x 365 days/year = 675.25 liters

When measuring the weight of water, remind students to subtract the weight of the container they use to hold the water. A liter of water weighs 1 kg (about 2.2 lb). One year's worth of drinking water, based on the figures above, would weigh 675.25 kg (1,488.7 lb).

Link to Space

If astronauts are to survive in their spacecraft, they must take *everything* with them, including basic resources such as air, food, and water. Spacecraft have weight and space limitations; such restrictions mandate water conservation on short trips and recycling on longer trips. Water cannot be compressed or lightened, and humans cannot severely cut back on water intake without jeopardizing their health.

Cosmonauts have recycled water, including aboard the Space Station *Mir*, but to date no American space mission has. Although Shuttle astronauts do not recycle water, they conserve weight and space by obtaining most of their water from the spacecraft's fuel cells. These cells produce electricity for the spacecraft by combining hydrogen and oxygen, a process that produces water as a by-product. The resulting water is then used for drinking, washing, and preparing food.

Plans for future spacecraft include a closed loop system for water. Water purification requires several methods: Multiple filters that remove particulates, heat and catalytic

kills bacteria. Water used for hygiene can be purified and used again. If students think this sounds disgusting, you can point out that the water they use at home has been used millions of times before by other people.

You Can Take it With You

Suggestions

Any size bottle can be used for this activity, but one-liter bottles are easy to carry. Students might want to tie string or strong yarn into a sling for their bottles.

Encourage the students to keep a log of the water they consume. They might want to attach a card and small pencil to their bottles to make record-keeping easier.

If students are interested in figuring out how much total water they use in a day, (see *More Ideas*), they will have to do some research. Appliance information booklets may tell them how much a particular appliance uses. You might want to challenge them to devise simple ways to figure out how much water goes down the drain while they use the sink or shower.

Sidney Gutierrez changes the filters of the air supply system on board the Space Shuttle. The system doesn't actually recycle air but conserves resources by filtering the air.

Amount Used	kg/liter	lb
Drinking	1.62	3.56
Water in food	1.50	3.30
Food rehydrating	0.79	1.75
Showering	2.72	6.00
Washing hands	4.08	9.00
Flushing urine	0.49	1.09
Total Needs	11.20	24.70

Amount Released	kg/liter	lb
Urine & fecal waste	1.59	3.51
Perspiring & breathing	2.28	5.02
Steam from preparing food	0.04	0.08
Hygiene	6.50	14.33
Steam from hygiene water	0.30	0.67
Flushing urine	0.49	1.09
Total Wastes	11.20	24.70

Table 1. Balancing Needs and Wastes for Astronauts. The average amount of water that an astronaut uses each day. Spacecraft designers use these figures to determine water needs for the space station. Excerpted from NASA document SSP 30262 Revision D, *Environmental Control and Life Support System Architectural Control Document Table 3.2.2-4 Nominal Crew Member and Cabin Water Balance: Non-extravehicular Activity Day. Note:* the amount of water for hand washing is for long duration space flight, and would be less than half for a short Shuttle flight.

Gardening in Space

Sustaining Humans

Goal

To explore some of the challenges of growing plants in space

Key Concepts

- Humans will need a renewable food source on extended space voyages.
- Plants use the energy from light to make organic material from air, water, and minerals.
- The weightless conditions of space flight provide special challenges when growing plants.

Overview

On long space voyages, astronauts will need to grow plants for food. The weightless environment of a spacecraft makes growing plants a challenge. For example, soil cannot be used because it creates unacceptable levels of free-floating dust. In this activity, students model current research into alternatives.

Materials

For each group:

Seeds
One or two clear containers with drainage holes
Lighting
Plant fertilizer
Plant-watering crystals (Acrylamide copolymer)

Preparation

- Purchase supplies. (See *Suggestions* on page 60.)
- Prepare a place with good lighting. (See *Suggestions*.)

Procedure

a. Prepare a weak fertilizer solution, using twice as much water as recommended in the directions.
b. Prepare the plant-watering crystals according to package directions, but substitute the fertilizer solution for water.
c. Spoon the hydrated crystals into containers.
d. Place seeds about 2 cm (0.75 in) apart on top of crystals.
e. Place the containers near good light.
f. About twice a week, rehydrate the crystals by placing the containers in a bowl of water for a few hours. Use fertilizer solution for every fifth watering.
g. Observe and record seeds' germination and growth.

Scientists study the challenges of maintaining closed systems by growing plants in this room which can be sealed so that nothing but energy enters or leaves.

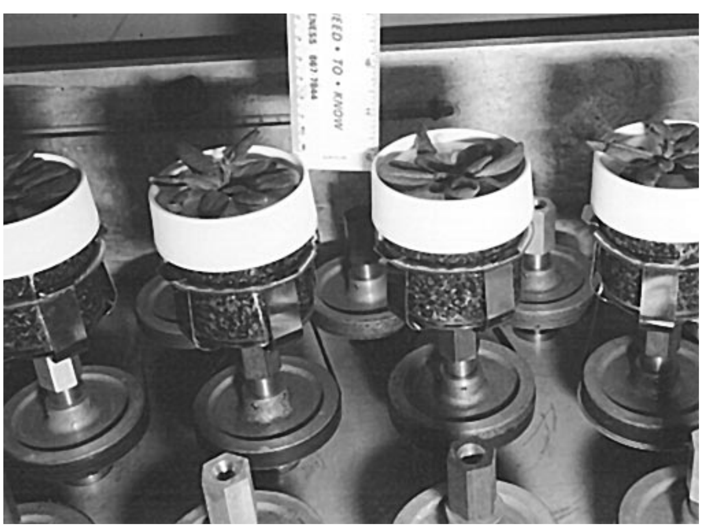
Gardening in Space

Observe

1. Describe the plant-watering crystals, including what they look and feel like.
2. Describe and draw the seeds before and after they germinate.

Interpret

3. Think of one major function that soil serves in plant growth. Do plant-watering crystals provide this function?
4. Fertilizer is often advertised as “plant food.” Is this an accurate description? Why or why not?



NASA KSC-392C-1075.04

This device, called a clinostat, slowly rotates plants and can be placed sideways to investigate the effects of gravity on plant growth.

Apply

5. Why might a gelatinous medium be more suitable than soil for growing plants in space?
6. What traits would be important for a plant that astronauts will grow on a long space voyage?
7. List pros and cons of taking plants on a long space journey.
8. Would you take live animals on a long space voyage? Why or why not?

In the Film

Students see a hydroponic facility at the Kennedy Space Center, Florida, where scientists are conducting tests to determine which plants grow quickly, easily, and can be entirely consumed.

Try This

Take equal *volumes* of moist soil and hydrated plant-watering crystals. Weigh each and record their weights and volumes. Allow both to dry completely—about two weeks. Compare their dehydrated weights and volumes to their hydrated weights and volumes.

What’s Going On?

Plant-watering crystals expand many times their original size when added to water, and become very light and compact when dried. Soil contains much less water and does not compact to any great degree when it dries. Its weight and volume—among other factors—make soil unsuitable for space travel.

NASM

Equal amounts of growing medium; hydrated (left) and dehydrated.

Gardening in Space

Look at This

These photographs show three types of plant-watering systems currently being researched. Describe how you think each might work.

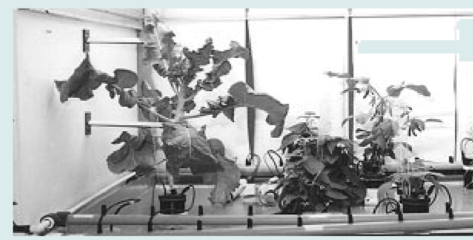
Photo A

KSC-393C-8.07

What's Going On?

Photo A shows a plant growing in agar, a gelatinous medium. *Photo B* shows roots that are in a slight vacuum inside the black pots, at about nine-tenths room air pressure. This keeps the water and dissolved minerals flowing past the roots without leaking. *Photo C* shows a setup where water slowly seeps through the walls of a porous ceramic tube. The roots are held around the wet tube by the white plastic sleeve.

Photo B



KSC-389C-2837/7

Photo C

KSC-389C-7122.05

To the Teacher

This activity should continue at least until the seedlings have several leaves. Make sure the students record their observations once a day, taking careful notes and drawing what they see. Sketching an object often helps a student see more details. The plant-watering crystals look and feel like clear, lumpy gelatin; descriptions of the seeds will no doubt vary.

The students probably already know the various functions of soil—anchoring roots, retaining moisture, delivering moisture and oxygen to plant roots, providing minerals that dissolve in water and can be absorbed through a plant's roots. The plant-watering crystals can perform each of these functions except the last, because they do not naturally contain minerals.

Fertilizer is not food for the simple reason that plants do not eat or ingest food. Plants grow, or add bulk to their structures, through photosynthesis. During this process, plants use energy from light to catalyze the production of organic matter such as cellulose, simple sugars, and proteins from inorganic substances such as carbon dioxide, water, and minerals. To synthesize proteins and other complex compounds, plants need phosphorous and nitrogen. Fertilizers provide these minerals when they are not present in the soil. Some plants obtain nitrogen by trapping insects that release nitrogen when they decay—important since they tend to grow in bogs which are poor in nitrogen.

To compare soil and soilless media, see Table 1, *Soil or Not?* on page 61. You might ask the students to compare the traits before sharing with them the information contained in the "Notes" column of the table.

Plants selected for a long space voyage have to be hardy, compact, palatable, and contain high food value and a wide range of amino acids. They should also be easy to pollinate, have short life cycles, and have seeds that are easy to collect for future plantings. Ideally, the entire plant should be edible or otherwise useful. Green algae meets most of these requirements, but many people find it unpleasant to eat. Researchers are testing the suitability of more complex plants such as lettuce, wheat, soy beans, potatoes, and rice for space travel.

Gardening in Space

On a space journey, plants would absorb carbon dioxide, produce oxygen, fulfill experimental purposes, serve as a food source, and provide recreation. But they also might produce harmful organic gases (that would be troublesome in the closed environment of a spacecraft), or might die and leave the astronauts without a source of food and oxygen.

Animals might be taken on long journeys into space for both experimental purposes and for enjoyment, but not as a food source. Animals require far more food to stay alive than they would provide if eaten.

Link to Space

Plants provide food, oxygen, water and air purification, and waste processing. We do not, however, have a great deal of experience with growing plants in space, and much more research must be done. For example, research now indicates that some plants may develop structural differences when grown in a weightless environment.

Roots of plants need to be provided with just enough water and nutrients for healthy growth. On Earth, soil performs this function extremely well and would probably perform well in orbit in the right container. However, many of its features make it impractical for use in space. (See Table 1. *Soil or Not*? page 61.) Researchers prefer agar to acrylamide copolymer because it allows better oxygen diffusion and is more easily washed away from plant roots. For classroom purposes, the crystals are easier to work with and do not require sterile techniques. Once a spacecraft arrives at a terrestrial planetary destination, plants might be grown in the planet's soils with proper additions of water and minerals.

Suggestions

Radishes are easy to grow, have interesting root systems, and mature quickly. You can also use Wisconsin Fast Plants, which have excellent growing and experimental guidelines (see *Resources* page 62).

Place the plants near a sunny window with an eastern or southern exposure or under fluorescent bulbs, which produce more of the wavelengths that plants use and less heat than incandescent lights. "Grow lights" are the best form of artificial lighting. They simulate sunlight and are more efficient to operate than other artificial lights, although their initial expense is higher. The ideal wattage varies from plant to plant and with your setup. The rule is to place light 7.5 cm (3 in) from germinating seedlings. As the plants mature, their top leaves should be about 20–30 cm (8–12 in) from the lamps.

Purchase plant-watering crystals—acrylamide copolymer sold under brand names Terra-sorb, SuperSorb, Moisture Mizer, and Hydra-Soil—from a local garden supply store. Do not use fertilizer formulated for soil for more than three weeks. It will not provide all of the minerals needed by plants growing in a soilless medium. Instead, purchase a fertilizer designed for *hydroponic media*.

See *Resources* for a list of suppliers of the materials listed above.

Norman Thagard and Roberta Bondar examine tiny shoots of plants that were grown in orbit. Knowing how plants respond to conditions aboard spacecraft is crucial for people planning to take extended trips into space.

Trait	Soilless Media	Soil	Notes
Dustiness	Virtually dust-free when hydrated	Very dusty	Dust continually drifts through the air of a spacecraft. Although air filters trap much of this dust, air quality decreases during a mission. Planting and harvesting in soil releases unacceptable amounts of dust.
Weight	Minimal when dehydrated even when dry.	Greater than soilless media even when dry	Considerable weight makes expensive to transport into space.
Volume	Minimal	Substantial	Considerable volume makes items expensive to transport into space.
Oxygen Content	Varies	Good if not waterlogged	Roots need oxygen for healthy growth. Liquid media needs to be aerated; some solid soilless media doesn't allow oxygen to pass through it very well.
Reusability	None	None	All growing media accumulate minerals and microorganisms that are difficult to remove. Both soil and soilless media must be discarded eventually. Gel and hydroponic media are easier to discard because dehydration reduces their mass.
Root Attachment	Minimal	Substantial	Researchers studying plant growth need to be able to easily remove plants from their growing media without damaging the roots.
Color	Transparent	Opaque	Clear media allow observation of root growth.
Presence of minerals	None natural	Some natural	Natural nutrients in soil can occur in different concentrations and can make nutrient control difficult.

Table 1. Soil or Not? Advantages and disadvantages of soil and other growing media.

Resources

Blue Sky Below My Feet. Three-part television series for 9–12 year olds. Show #2 Mission: *Fiber and Fabrics* (Item No. BS 1071) depicts how space suits are made and discusses why we wear certain fabrics for sports and others for our jobs. Available from National 4-H Council, 7100 Connecticut Ave, Chevy Chase, MD 20815 [301-961-2934].

The Dream is Alive. [Motion Picture]. Toronto: Imax Systems Corp., 1985, 37 min. color. Copyrighted by the Smithsonian Institution and Lockheed Corp. This 37-minute film lets the viewer share the astronauts' experiences of working, eating, and sleeping in space. This film is available to individual consumers from videotape retailers.

Flying by the Planets: The Video. Spectacular, computer-generated footage developed by the Jet Propulsion Laboratory. Available from The Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, CA 94112 [415-337-2624].
Liftoff to Learning: Go for EVA. Outlines the history and development of space suits. Gives a detailed explanation of the design and functions of today's Shuttle space suits. NASA CORE #007.06-26.

Liftoff to Learning: Space Basics. Computer graphics and visual demonstrations cover weightlessness, and how spacecraft travel into space and remain in orbit. There is a good section on free fall toward the end of the program. Geared to grades 5–8, this film includes a teacher resource guide. NASA CORE #007.6-25.

Look Up. Series of 23 programs geared to grades 4–6. Children investigate the science behind flight, space travel, satellites, planets, stars, and weather and bring it to life through animation, scientific experiments, film footage, and music. Available from Modern Talking Pictures, 500 Park St., N., St. Petersburg, FL 33709, [1-800-237-4599].

Mechanical Universe, High School Adaptation. Introductory physics course on videotape. Of special interest to this study are Quads 1, 3, and 4, which cover Newton's laws, orbital motion as free fall, navigating in space, the law of falling bodies, inertia, moving in circles, Kepler's laws, and curved space. Available from Southern California Consortium, Attn: Marketing Department, 5400 Orange Ave., Suite 215, Cypress, CA 90630 [714-828-5770].

Skylab Physics. Shows everyday investigations performed in the weightless environ ment aboard Skylab, America's first space station. Teacher's guide discusses the basic physics and suggests classroom activities. Produced by and available from AAPT. Also available to non-members from Ztek Company, PO Box 1055, Louisville, KY 40201-1055 [1-800-247-1603].

Space Education. Excellent series of films for junior and senior high school students on space science topics. Program subtitled Making Sense of Our Senses explains the three human sensory systems used to detect motion. Footage shows how these systems function on Earth and in a weightless environment. Microgravity documents experiments conducted aboard the NASA KC-135 jet by astronauts. Available from Journal Films, 1560 Sherman Ave., Suite 100, Evanston, Ill., 60201 [1-800-323-5448].

Space Shuttle. (Laserdiscs). This rich resource contains many photographs and video clips of life on the Space Shuttle. Sold separately or as part of a three-part series by Optical Data Corporation. 30 Technology Drive, Box 4919, Warren, NJ 07060 [1-800-524-2481].

STS-40 Post Flight Press Conference. Post-flight, astronauts narrate their version of home movies from their June 1991 mission. Information is not highly detailed, but is generally very interesting. Highlights include vestibular experiments (using a rotating chair); blood pressure investigations; jellyfish responses to a weightless environment. NASA CORE # 007.7-05.

Supplies

Grow lights are often sold at hardware and garden supply stores. Also available from Duro-Lite Lamps, Inc, Duro-Test Corp., 2321 Kennedy Blvd., North Bergen, NJ 07047 [1-800-289-3876].

Hydroponic media may be available at your local garden supply center or by mail. One supplier is Great Bulbs of Fire, RR2 Box 815, New Freedom, PA 17349 [717-235-3882].

Plant-watering crystals (Acrylamide copolymer) are sold at many garden supply stores under brand names such as SuperSorb, Moisture Mizer, and HydraSoil. Also available under the brand name TerraSorb from W. Atlee Burpee & Co., 300 Park St., Warminster, PA 18974 [1-800-888-1447].

Radish seeds (recommended variety Cherry Belle) are often sold at garden supply stores. Also available from W. Atlee Burpee & Co., 300 Park St., Warminster, PA 18974 [1-800-888-1447].

Wisconsin Fast Plants are available solely from Carolina Biological Supply Company, 2700 York Rd., Burlington, NC 27215 [1-800-334-5551].

Miscellaneous

Music evocative of space exploration includes: *The Planets.* Orchestral suite by Gustav Holst. *Mysterious Mountain.* Orchestral work by Alan Hovhaness. *Calm Sea and a Prosperous Voyage.* Overture by Felix Mendelssohn. Also *Sprach Zarathustra.* Symphonic poem by Richard Strauss. (Famous as theme music for the film, *2001: A Space Odyssey.) Symphonia Antarctica.* Symphony No. 7., and *Toward the Unknown Region.* Song for chorus and orchestra. Both by Ralph Vaughan Williams.

NASA photographs printed in this book can be ordered as follows: NASA H and HC numbers can be ordered from Bara Photographic, P.O. Box 486, Hyattsville, MD 20710 [301-322-7900]. NASA JPL numbers can be ordered from Newell Color Lab 221 N. Westmoreland Avenue, Los Angeles, CA 90004-4892 [213-380-2980]. NASA JSC numbers can be ordered from NASA Johnson Spaceflight Center, Media Services, P.O. Box 58425, Houston, TX 77258 [713-483-4231]. NASA NSSDC numbers can be ordered from National Space Science Data Center, Code 633.4, Goddard Space Flight Center, Greenbelt, MD 20771 [301-344-6695].

NASA Select Satellite TV service. Transmits informational programming on space and aeronautics. Individuals can access NASA Select through their local cable television company (if they offer this service) or by using a satellite dish receiver. Contact NASA CORE for an informational flyer.

Space Link. A NASA-sponsored computer network providing current NASA news, educational services information, and classroom materials. Contact NASA, Marshall Space Flight Center, Code CA21, Marshall Space Flight Center, Huntsville, Alabama, 35812 for information or direct dial modem [205-895-0028].

NASA JSC S40-206-014

Typical scales are useless in a weightless environment. Instead astronauts measure their mass by using this swinging chair. Tamara Jernigan times the swing as the chair moves back and forth. The period of swing varies with mass.

62

Resources

Teaching Materials

Space Simulation by L. Jerry Bernhardt and Larry McHaney. Instructions for a simulated shuttle mission, including plans, diagrams, project goals, and implementation. Published in New York by Delmar Publishers, Inc., 1992.

Living and Learning in the Space Age by Jeffrey Crelinsten. Information and classroom activities geared for grades 7–10. Topics include living and working in space, satellite communications, remote sensing, and space science technology. Available from Fitzhenry and Whiteside Ltd., 195 Allstate Parkway, Markham, Ontario, L3R4T8.

Space Suit Guidebook (PED-117) and Wall Chart (WAL 114). NASA publications. Book and poster set outlining functions of the different components of the space suit. Request by number from NASA Educational Publications Division, Code FEO, Washington, D.C. 20546 [202-453-1287].

Suited for Spacewalking: A Teacher's Guide with Activities. Information and classroom activities related to space suits. Request as NASA publication # EP-279 from NASA Educational Publications, Code FEO, Washington, D.C. 20546 [202-453-1287].

Books

Armbruster, Ann. *Astronaut Training.* New York: F. Watts, 1990. Overview of selection, training, and work of today's astronauts as well as a history of the early astronauts.

Bernards, Neal. *Living in Space: Opposing Viewpoints.* San Diego: Greenhaven Press, 1990. Outlines issues and opposing viewpoints on various aspects of space exploration.

Blumberg, Rhoda. *The First Travel Guide to the Moon: What to Pack, How to Go, & What to See When You Get There.* New York: Four Winds Press, 1984. This fanciful book gives students practical advice on how to prepare for and what to expect on a vacation trip to the Moon.

Clark, Phillip. *The Soviet Manned Space Program.* New York: Orion Books, 1988. Encyclopedic, chronologic analysis of the Soviet manned space program from Gagarin to current space operations.

Collins, Michael. *Flying to the Moon and Other Strange Places.* New York: Farrar, Straus, and Giroux, 1976. Author discusses his early career, his training for space flight, his trips into space, and the possibilities for life and flight in space. For a student audience.

DeHart, Roy L., ed. *Fundamentals of Aerospace Medicine.* Philadelphia: Lea & Febiger, 1985. Textbook on aerospace medicine. Topics include environmental challenges posed in flight and medical factors important when selecting crew members.

Embury, Barbara. *The Dream is Alive.* New York: Smithsonian Institution Press, 1990. Beautifully illustrated book describes astronauts' experiences aboard the NASA space shuttle, including weightlessness, the ways they eat and bathe, and the special kinds of exercises they do in space.

Joels, Kerry Mark and Gregory P. Kennedy. *The Space Shuttle Operator's Manual.* New York: Ballantine Books, 1982. Detailed, technical illustrations and charts covering many aspects of the Shuttle program. Text and diagrams appropriate for middle school students. Ideal resource for flight simulations or for building scale models.

Kelley, Kevin W. *The Home Planet.* Reading, MA: Addison-Wesley, 1988. A beautiful book filled with photographs of Earth from space with written reflections by space explorers past and present.

Lebedev, Valentin. *Diary of Cosmonaut: 211 Days in Space.* New York: Bantam Books, 1990. Candid account detailing the personal experiences of a cosmonaut during his 1982 mission. Includes how he lived, his frustrations, and where he found strength.

Miles, Frank and Nicholas Booth, eds. *Race to Mars: The ITN Mars Flight Atlas.* London: MacMillan, 1988. Outlines challenges involved with possible future, human space flights to Mars. Briefly outlines past robotic missions to the planet and its satellites. Well documented and written for a general audience.

Neal, Valerie. *Where Next, Columbus? Essays on Exploration.* NY: Oxford University Press, 1994. A companion to the Where Next, Columbus? exhibition at the National Air and Space Museum, this book is a collection of informal essays by noted authors who contemplate the meaning of past exploration, present challenges, and prospects for future space exploration.

Oberg, James E. *Pioneering Space: Living on the Next Frontier.* New York: McGraw-Hill, 1986. Very readable; designed for a general audience. Details experiences of living in space including communications, gardening, psychology, robots, and using the bathroom.

Pogue, William. *How do you go to the bathroom in space?* New York: Tor, 1991. Skylab Astronaut Pogue responds to over 180 frequently asked questions about space in an easy-to-use format. A few of the cited details are dated; however, the majority of the book is excellent for a general audience.

Trefil, James E. *Living in Space.* New York; Scribner, 1991. Outlines how a space colony might be established. Deals with underlying science and technology necessary to the task.

Vogt, Gregory. *The Space Shuttle.* New York: F. Watts, 1983. Discusses experiments, proposed by high school students, that have been performed aboard Skylab and gives advice to those interested in similar space research competitions.

Articles and Booklets

Cooper, Jr., Henry S.F. "A Reporter at Large (Space Station)." *New Yorker Magazine*, (Aug. 30, 1976): 34–66, (Sept. 6, 1976): 34–70. An extensive two-part article that tells the story of Skylab, America's first orbiting space station. Details some of the astronauts' interpersonal difficulties.

Corey, Kenneth A. and Raymond M. Wheeler. "Gas Exchange in NASA's Biomass Production Chamber." *BioScience*, Vol. 42, No. 7 (July/Aug. 1992): 503–509. Technical article detailing a preprototype closed human-life-support system.

Grossman, John. "The Blue Collar Spacesuit." *Air and Space Magazine*, Vol. 4, No. 4 (Oct/Nov 1989): 58–67. Discusses two space suit designs for possible use aboard the next space station.

Guidance on Radiation Received in Space Activities (1989): Report # 98. A 200-page booklet outlining the radiation environment of space and recommendations for space travelers. Available from National Council on Radiation Protection (NCRP), 7910 Woodmont Ave., Suite 800, Bethesda, MD 20814 [301-657-2652].

Manned Space Flight. Bibliography listing sources on the development of manned space flight from its beginning to the present. Request TB 81-10, revised 1989, LC Science Tracer Bullet, from the Science Reference Section, Science and Technology Division of the Library of Congress, 10 First Street, SE, Washington, D.C. 20540.

NASA Scientific and Technical Publications Catalog. Lists thousands of articles for purchase. Titles include "Aerospace Medicine and Biology: A Continuing Bibliography;" "Fuel Utilization During Exercise After 7 Days of Bedrest;" "Reliability of a Shuttle Reaction Timer;" and "USSR Life Science Digest." Available from NASA Scientific and Technical Information, NASA Center for Aerospace Information, 800 Elkridge Landing Rd., Linthicum, MD 21090 [301-621-0146].

Odyssey Magazine. Student magazine on space-related topics geared to grades 4–9. Articles include activities and current events in space science. Individual or classroom subscriptions available from Cobblestone Publishing, Inc., 7 School St., Peterborough, NH 03458 [1-800 821-0115].

Films, Videos, and Videodiscs

Note: Any video listed from NASA CORE can be ordered from NASA CORE, Lorain County JVS, 15181 Route 58 South, Oberlin, OH 44074 [216-774-1051 ext. 293]

2001: A Space Odyssey. [Motion Picture]. Los Angeles: MGM Films, 1968, 143 min. color. Unusual story line aside, this film has some wonderful sequences depicting the silence of space and life aboard a rotating spacecraft. This film is available to individual consumers from videotape retailers.

Developed to accompany the National Air and Space Museum's latest IMAX® film, *Destiny in Space*, this booklet examines our future prospects for space exploration. The film is shown in the Museum's Langley Theater as well as in other IMAX/OMNIMAX theaters worldwide. (For show times at the National Air and Space Museum, call the theater's recorded information line on 202-357-1686. For showings at other locations, contact the theaters listed on the inside back cover.)

The National Air and Space Museum is open to the public every day, except December 25, from 10:00 a.m. to 5:30 p.m. Summer hours may vary. The Museum is located at Independence Avenue between 4th and 7th Streets, SW, in Washington, D.C. Admission to the Museum is free; there are small fees for shows and films presented in the Einstein Planetarium and on the giant IMAX screen in the Langley Theater.

Group reservations for tours, films, planetarium shows, and science demonstrations must be made in advance. Reservations are accepted by mail on a first-received, first-served basis between three and eight weeks in advance. For more information, request a Programs Brochure from the National Air and Space Museum, Educational Services Department MRC-305, Washington, D.C. 20560 [202-357-1400 voice] [202-357-1505 TTY]. The Programs Brochure also describes the Museum's wide variety of programs geared to general audiences.

For information on services for teachers, contact the Teacher Services Coordinator. For information on student internships, contact the Student Services Coordinator at the following address: Educational Services Department MRC-305, Washington, D.C. 20560 [202-786-2524].

The IMAX film, *Destiny in Space* is presented as a public service by the Smithsonian Institution's National Air and Space Museum and Lockheed Corporation in cooperation with the National Aeronautics and Space Administration. It is produced by Imax Space Technology, Inc. and distributed by Imax Corporation.

Author and illustrator: Carolyn E. Schmidt
Writer-editor: Carolyn Duckworth
NASM editor: Helen Morrill
Cartoonist: Chris Major
Designer: Don Schaaf & Friends, Inc.

Printed on recycled paper in the United Stated of America W

Cover photos:
The large image is of Venus and was produced using data from *Magellan*. The spacecraft's radar was able to peer through dense clouds to map the surface, revealing detail as never before. Generally, the brighter areas show rough surfaces, the darker areas smooth.(NASA JPL P-42383)

The tinted photographs illustrate three modes of space exploration; robotic spacecraft, telescopes, and astronauts. [Shown, top, *Voyager* NASA JPL P-19795; middle, *Hubble* being released from the Space Shuttle; and bottom, astronauts working in orbit.] The faint image in the lower right is a computer generated three-dimensional perspective view of Maat Mons, Venus, using data from the *Magellan* spacecraft.

The IMAX film *Destiny in Space* premiered in Washington, DC in June 1994. Check with your local IMAX/OMNIMAX theater to find out when it will be showing in your area:

AUSTRALIA
Coomera, Queensland
Dreamworld
(07) 573-1133

Perth, Western Australia
Omni Theatre City West
(09) 481-5890

Townsville, Queensland
Great Barrier Reef Wonderland
(07) 721-1481

AUSTRIA
Vienna
Imax Filmtheater
1-894-0148

BELGIUM
Brussels
Kinépolis
24-78-04-50

CANADA
Calgary, Alberta
IMAX Theatre at Eau Claire Market
(403) 974-4629

Edmonton, Alberta
Edmonton Space & Science Centre
(403) 452-7722

Hull, Québec
Canadian Museum of Civilization
(819) 776-7000

Montréal, Québec
Le Vieux-Port de Montréal
(514) 496-4629

Niagara Falls, Ontario
Niagara Falls IMAX Theatre
(905) 358-3611

Quebec City, Quebec
Naturalium de Quebec
Opens 1995

Regina, Saskatchewan
Saskatchewan Science Centre
(306) 522-4629

Sudbury, Ontario
Science North
(705) 522-3701

Toronto, Ontario
Ontario Place
(416) 314-9900

Vancouver, British Columbia

CN IMAX Theatre at Canada Place
(604) 682-4629

Science World BC
(604) 268-6363

Winnipeg, Manitoba
IMAX Theatre at Portage Place
(204) 956-4629

DENMARK
Copenhagen
Tycho Brahe Planetarium
33-12-12-24

FRANCE
Paris
Cité des Sciences et de l'Industrie
(1) 40-05-80-04

Dôme IMAX à la Défense
(1) 46-92-45-45

Poitiers
Parc du Futuroscope
49-49-30-00

GERMANY
Bruhl
Phantasialand
2232-360140

Munich
Deutsches Museum
89-211-25180

GREAT BRITAIN
Bradford, West Yorkshire
National Museum of Photography, Film & Television
(0274) 727-488

HONG KONG
Kowloon
Hong Kong Space Museum
(852) 734-2747

INDONESIA
Jakarta
Taman Mini Indonesia Indah
(21) 840-1021

ISRAEL
Rishon Le Zion
OMNIMAX at the Downtown Centre
Opens November 1994

JAPAN
Chiba
Fujitsu Dome Theatre
(43) 299-3215

Hamaoka
Hamaoka Nuclear Exhibition Center
(53) 786-3481

Ichikawa
Chiba Museum of Science & Industry
(473) 79-2000

Kagoshima
Kagoshima Municipal Science Hall
(99) 250-8511

Kitakyushu
Space World
(93) 672-3520

Matsuyama
Matsuyama Multi-purpose Community Centre
(89) 943-8228

Nagano
Azumino IMAX Theatre
Opens 1995

Nagashima
Nagashima Spaland
(59) 445-1111

Nagoya
Nagoya Port Aquarium
(52) 654-7080

Omiya
Omiya Information Media Culture Centre
(48) 647-0011

Osaka
Osaka Science Museum
(6) 444-5656

Suntory Museum
Opens October 1994

Tennoji Park
(6) 771-1323

Sapporo
Sapporo IMAX Theatre
(11) 207-5255

Sasebo
Saikai Pearl Sea Centre
Opens July 1994

Shima
Spanish Village
(59) 957-3337

Tokorozawa
Tokorozawa Aviation Museum
(42) 996-2225

Tokyo
Adachi Children's Museum
(35) 243-8161

Yokohama
Yokohama Science Centre
(45) 832-1166

MEXICO
Leon
Cultural Centre
Opens September 1994

Mexico City
Papalote Museo del Niño
5-273-3061

Monterrey, Nuevo Leon
Centro Cultural Alfa
83-565225

Puebla, Puebla
Planetario Puebla
22-352099

Tijuana, Baja California Norte
Centro Cultural Tijuana
66-841111

Villahermosa, Tabasco
Planetario Tabasco 2000
93-133841

Xalapa, Veracruz
Museo de Ciencia y Tecnologia
28-125110

NETHERLANDS
Rotterdam
IMAX Rotterdam
10-404-9244

The Hague
Omniversum
70-354-7479

PORTUGAL
Lisbon
Vila Franca de Xira
Opens November 1994

SINGAPORE
Singapore Science Centre
560-3316

SOUTH KOREA
Seoul
63 IMAX Theatre
(2) 789-5505

Taejon
Expo Science Park
(42) 866-6400

SPAIN
Barcelona
Port Vell IMAX Theatre
Opens December 1994

Seville
Cine Espacial Alcatel
(5) 490-4510

SWEDEN
Stockholm
Swedish Museum of Natural History
8-666-5103

TAIWAN
Kaoshiung
National Museum of Science and Technology
Opens 1995

Taichung
National Museum of Natural Science
(04) 322-6940

Taipei
Children's Recreational Centre
(02) 593-2211

Taipei Observatory
Opens 1995

UNITED STATES
Alamogordo, New Mexico
Space Center
(505) 437-2840

Atlanta, Georgia
Fernbank Museum of Natural History
(404) 370-0019

Baltimore, Maryland
Maryland Science Center
(410) 685-5225

Boston, Massachusetts
Boston Museum of Science
(617) 723-2500

Branson, Missouri
Ozarks Discovery IMAX Theater
(800) 419-4832

Charlotte, North Carolina
Discovery Place
(704) 845-6664

Chicago, Illinois
Museum of Science and Industry
(312) 684-1414

Cincinnati, Ohio
Museum Center at Union Terminal
(513) 287-7000

Cleveland, Ohio
Great Lakes Museum
Opens 1995

Dayton, Ohio
U.S. Air Force Museum Foundation
(513) 253-4629

Denver, Colorado
Denver Museum of Natural History
(303) 370-6322

Detroit, Michigan
Detroit Science Center
(313) 577-8400

Fort Lauderdale, Florida
Museum of Discovery & Science
(305) 467-6637

Fort Worth, Texas
Fort Worth Museum of Science & History
(817) 732-1631

Galveston, Texas
Moody Gardens
(409) 744-4673 ext. 240

Gurnee, Illinois
Six Flags Great America
(708) 249-1776

Hampton, Virginia
Virginia Air and Space Center
(804) 727-0800

Hastings, Nebraska
Hastings Museum
(402) 461-2399

Honolulu, Hawaii
Hawaii IMAX Theatre
(808) 923-4629

Houston, Texas
Houston Museum of Natural Science
(713) 639-4600

Space Center Houston
(713) 244-2100

Huntsville, Alabama
U.S. Space & Rocket Center
(205) 837-3400

Hutchinson, Kansas
Kansas Cosmosphere and Space Center
(316) 662-2305

Jersey City, New Jersey
Liberty Science Center
(201) 451-0006

Kennedy Space Center, Florida
Space Port USA
(407) 452-2121

Laie, Hawaii
Polynesian Cultural Center
(808) 293-3280

Las Vegas, Nevada
Caesars Palace
(702) 731-7901

Little Rock, Arkansas
Aerospace Education Center
Opens 1995

Los Angeles, California
California Museum of Science and Industry
(213) 744-2014

Louisville, Kentucky
Museum of History and Science
(502) 561-6100

Lubbock, Texas
Science Spectrum
(806) 745-2525

Memphis, Tenessee
Pink Palace Museum
Opens December 1994

New Orleans, Louisiana
Aquarium
Opens 1995

New York, New York
American Museum of Natural History
(212) 769-5650

Sony Imax Theater
Opens November 1994

Norwalk, Connecticut
The Maritime Center
(203) 852-0700

Philadelphia, Pennsylvania
Franklin Institute Science Museum
(215) 448-1200

Pittsburgh, Pennsylvania
Carnegie Science Center
(412) 237-3400

Portland, Oregon
Oregon Museum of Science and Industry
(503) 797-4000

Richmond, Virginia
Science Museum of Virginia
(804) 367-0000

San Antonio, Texas
Alamo IMAX Theater
(210) 225-6605

San Diego, California
Reuben H. Fleet Space Theater and Science Center
(619) 238-1233

Sandusky, Ohio
Cedar Point Amusement Park
(419) 627-2388

Santa Clara, California
Paramount's Great America
(408) 988-1776

Scottsdale, Arizona
IMAX Theatre at Scottsdale Galleria
(602) 949-3100

Seattle, Washington
Pacific Science Center
(206) 443-4629

Seattle Omnidome
(206) 622-1868

Shakopee, Minnesota
Valleyfair Family Amusement Park
(612) 445-7600

Spokane, Washington
Riverfront Park
(509) 625-6600

St. Louis, Missouri
St. Louis Science Center
(314) 289-4444

St. Paul, Minnesota
The Science Museum of Minnesota
(612) 221-9488

Tampa, Florida
Museum of Science and Industry
Opens 1995

Tusayan, Arizona
Grand Canyon IMAX Theatre
(602) 638-2203

Washington, DC
National Air and Space Museum
(202) 357-1675

West Yellowstone, Montana
Yellowstone IMAX Theatre
(406) 646-4100